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(51) International Patent Classification ⁶ : G09B 5/12		A1	(11) International Publication Number: WO 97/44766
			(43) International Publication Date: 27 November 1997 (27.11.97)
(21) International Application Number: PCT/US97/08685		(81) Designated States: AL, AM, AU, AZ, BA, BB, BG, BR, BY, CA, CN, CU, CZ, EE, GE, GH, HU, IL, IS, JP, KG, KP, KR, KZ, LC, LK, LR, LT, LV, MD, MG, MK, MN, MX, NO, NZ, PL, RO, RU, SG, SI, SK, TJ, TM, TR, TT, UA, US, UZ, VN, YU. ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 22 May 1997 (22.05.97)			
(30) Priority Data:			
08/651,422	22 May 1996 (22.05.96) US		
60/037,108	31 January 1997 (31.01.97) US		
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This invention relates to a system and method for interactive, adaptive, and individualized computer assisted instruction. This invention includes an agent (108) for each student (101) which adapts to its student, and provides individualized guidance to the student and controls the augmented computer assisted instructional materials. The instructional materials of this invention are augmented to communicate the student's performance and the material's pedagogical characteristics to the agent, and to receive control from the agent. In a preferred embodiment, the agent maintains data reflecting the student's pedagogic or cognitive characteristics in a protected and portable media in the personal control of the student. Preferably, the content of the communication between the agent and the materials conforms to specified interface standards, so that the agent acts independently of the content of the particular materials. Also preferably, the agent can project using various I/O modalities integrated engaging, lifelike display persona(e).

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**AGENT BASED INSTRUCTION
SYSTEM AND METHOD**

1. FIELD OF THE INVENTION

5 This invention relates to a system and method for
interactive, adaptive, and individualized computer-assisted
instruction of students, preferably implemented on network
connected computers. More particularly the system and method
includes for each student an agent adapted to that student
10 which monitors its student's instructional behavior, responds
to teacher direction, and controls the instructional
progress, and guides its student, all of which constitute one
aspect of a virtual tutor. Preferably, the viewable on-
screen aspect of the agent includes customizable multimedia
15 presentation personae, which constitute a further aspect of a
virtual tutor.

2. BACKGROUND OF THE INVENTION

 The application of computers in education has been
20 limited by several problems, including a failure to provide
systems that adapt or individualize to each student, a
failure to integrate systems effectively into the existing
classroom in elementary and secondary schools, and a failure
to exploit technological developments. Although during the
25 last three decades, a number of interactive educational
techniques have been implemented on computers, all these
systems lack the ability to recognize and to adapt to each
student's individual characteristics. The common motivation
for interactive educational techniques was the recognition
30 that individual student interaction fosters learning to a
greater degree than mere passive exposure to a fixed pace
presentation (Kulik et al., 1986, Effectiveness of computer-
based adult learning: a meta-analysis, *Journal of educational
computing research* 2:235-252; Kulik et al., 1983, Effects of
35 computer-based teaching on secondary school students, *Journal
of educational psychology* 75:19-26). Existing, interactive
educational techniques have many variants: programmed

instruction, mastery learning, audio-tutorials, direct instruction, personalized system of instruction, precision teaching, fluency learning and others (Engleman et al., 1982, *Theory of instruction: Principles and Applications*, 5 Irvington, New York; Keller, 1968, "Goodbye, teacher...", *Journal of Applied Behavior Analysis* 1:79-89; Lindsley, 1990, Precision teaching: By teachers for children, *Teaching Exceptional Children* 22:353-359; West et al., 1992, *Designs for Excellence in Education: the Legacy of B.F. Skinner*, 10 Sorris West, Inc., Longmont, Colorado, pp. 147-160). Several systems have attempted to harness the interactivity of the computer for these interactive educational techniques. In early work, for example, text-based programmed instruction was converted to computer format and implemented on time- 15 shared systems. This early development was extended with more sophisticated computer-assisted instruction ("CAI"), also known as compute based training ("CBT").

In CAI, for example, the computer acts as a teaching machine. A program presents instructional displays, accepts 20 student responses, edits and judges those responses, branches on the basis of student responses, gives feedback to the student, and records and stores the student's progress. Examples of CAI systems include those of Carbonell, 1970, AI in CAI, an artificial intelligence approach to computer- 25 assisted instruction, *IEEE Transactions on Man-machine Systems*, 11:190-202; Osin, 1984, CAI on a national scale, *Proc. 4th Jerusalem Conf. on Information Technology*, pp 418-424; Seidel 1971; Koffman et al., 1975, Artificial intelligence and artificial programming in CAI, *Artificial* 30 *Intelligence* 6:215-234. Effective CAI instructional materials for a limited number of specific topics have been developed, as have special "authoring languages," which assist instructional developers on the tasks of designing instructional materials. U.S. Patent No. 5,310,349 is 35 exemplary of such CAI systems.

However, existing CAI systems do not adapt to their students. These systems merely sequence students through

educational materials, based only on student performance during a current lesson and using only parameters such as recent responses and pre-requisite patterns. These systems do not gather or use information on more comprehensive
5 student characteristics, such as past student performance, student performance on other courses, student learning styles, and student interests.

A greater deficiency is that existing CAI systems do not recognize characteristics of their individual students. They
10 cannot be individualized or made responsive to their students styles. Thereby, these system ignore those roles of a human tutor that can be of unparalleled significance in the education of an individual. The human tutor assists in scheduling and prioritizing and in maintaining interest
15 through proper reinforcement and knowledge of student abilities and preferences. A human tutor observes and addresses patterns of errors and maintains a consistent manner of interaction across a broad range of subject matters and activities. Moreover, a human tutor effectively
20 integrates the cognitive, personal and social aspects of the instructional situation. In other words the human tutor provides a level of individualization based on student styles and on requirements of the instructional task. Furthermore, the human tutor provides an equally effective interaction
25 with the teacher by accepting individualized instructions, collecting data and providing detailed reports. By failing to address these higher order services and roles of an effective human tutor, existing CAI systems fail to fully engage their students and thus fail instruct as well as
30 possible.

Additionally, a further problem of computer assisted instruction, particularly in primary and secondary school settings is poor integration into the rest of the school curriculum and often poor quality of the educational
35 materials. In application to elementary and secondary schools, two main patterns of instructional computer use prevail, which illustrate the compromises prevalent today.

In one pattern, the integrated learning system ("ILS") is a dedicated installation that is used in schools to teach basic strands of reading, mathematics and related topics, spelling, writing, and other language arts, from grades one to six, or perhaps to eight or nine (EPIE, 1990, *Integrated Instructional Systems: an Evaluation*, Educational Products Information Exchange, Hampton Bays, N.Y.). The paradox with this pattern, regardless of the quality of the instruction offered by these systems, the work of students in ILSs bears little relation to what goes on in the classrooms in that very same topic. The fundamental reason is that the teacher cannot influence or respond meaningfully to variations in student progress or to relations between the CAI curriculum and the classroom text, materials and activities. This is the case even where the ILS installation produces reports in some detail as to each student's progress and standing.

The second pattern of computer use in schools is that of stand-alone short units on specific topics (TESS, 1996, *Database of Educational Software Systems*, Educational Products Information Exchange, Hampton Bays, N.Y.). These can be hypercard programs, simulations, or games, and are usually separate from the basic classroom curriculum. Though occasionally of excellent quality, the paradox here is that these products are usually chosen for enhancement, possible optional, and do not account for a major component of school related instruction. No records are kept or returned regarding student performance. These programs have not made a major contribution to school instruction.

Finally, computer assisted instruction systems have ignored or under utilized such important developments in computer technology over the past four years as agent-based system, client-server systems, and networking systems. Though now an active field with a wide spectrum of activities from research to commercial applications, application of agent-based systems in educational, instructional, and homework tasks has not been explored. Software systems for intelligent agents have successfully applied in travel

arrangements, email management, meeting scheduling, stock portfolio management, and gathering information from the Internet (Maes, 1994, Agents that reduce work and information overload, *Communications of the ACM* 37:30-40). In all these applications, software agents perform tasks on the user's behalf, receiving only general instructions from their user but then executing detailed tasks with considerable independence and initiative. In client-server systems, these agents can operate in the client, the server, or both.

10 Recently, adaptive and personalized agent based systems have begun to be developed. Systems with adaptive agents, agents which learn from experience, has made gains with new techniques continually identified. Adaptive agents have permitted new commercially viable adaptive systems

15 implemented across networks. In these systems, an agent is a "go-between," mediating relations in a manner whose function is understood with details being left to the agent itself. The agent acts as a "stand-in" for its user, who is thus freed from direct manipulation of the network. In

20 instructional applications, there is an unmet need for an agent who serves two users: the school system and the individual student. This is the well-known role of the teaching assistant/tutor. Maes, 1994, and others have extended the metaphor of agent to that of personal assistant,

25 an agent who learns some important characteristics of its user, and adapts its behavior accordingly. Agents can learn by a mixture of methods: observation, receiving feedback from its user, receiving instructions from the user, and consulting other agents concerning "similar problems." To

30 combine the important properties of competence, trust, and intimacy that a personal assistant should have, an agent should be in touch with relevant data, represent important facts in a reliable manner, and engage with its user in a personal and fundamentally sympathetic -- at times playful --

35 manner. Approaches to the creation of agents with personal characteristics have begun to be explored. In this work, relevant techniques are found in the tradition of film

animators who, through the portrayal of emotions, gave their characters the illusion of life.

Moreover, computer assisted instructional systems have only haphazardly exploited the potential of client-server systems and networking technologies. Client-server architectures have emerged as the principal architecture of distributed computer systems. Client systems, running under sophisticated windowing operating systems, can support advanced object based software applications, including high speed graphics, animation and audio output. Servers can store gigabytes of data and programs at central or distributed locations at quite reasonable cost. Object oriented database systems have been developed to store structured data on servers.

Client systems, in a striking change from only several years ago, now virtually all have multimedia capabilities, including high quality graphics, sound, and at least limited video playback capability. Text-to-speech software is presently available for use with these systems, and speech recognition software is on brink of widespread commercial acceptability on low cost platforms. New authoring tools support graphical methods for generation of multimedia presentations and computer based instructional materials having corresponding sequencing logic.

Clients and servers can be linked remotely with increasing convenience and decreasing cost. The Internet has emerged as a means of providing an inexpensive means of connecting computers to provide effective communications and access to information and other resources such as software. Further Internet developments that made the Internet truly universal include the HTML and the HTTP protocols, which provide platform independent access to hyperlinked multimedia information, and the Java™ programming language, which provides platform independent software for Internet applications programming. Subsets of the Internet -- intranets -- have become an increasingly important means for disseminating information and enabling communication within

constrained domains, such as a single school system or corporate enterprise.

Existing CAI systems have not addressed these functional deficiencies nor have they exploited the possibilities of
5 existing technologies.

Citation of references hereinabove shall not be construed as an admission that such a reference is prior art to the present invention.

10

3. SUMMARY OF THE INVENTION

The Agent Based Instruction ("ABI") system of this invention is a system and method for interactive, adaptive, and individualized computer-assisted instruction and homework, preferably implemented on network connected
15 computers, that overcomes these problems by providing the following objects in preferred and alternative embodiments. This invention provides a more effective system responsive to the needs of several parties interested in education.

An important object of this invention is to provide the
20 student with a virtual tutor, by having agent software ("agent") adapted to each student that offers a high quality of individualized student interaction and that manages or controls instruction in a manner approximating a real tutor. The agent exercises management or control over the computer-
25 assisted instruction materials and provides information and help to the student, both synchronously and asynchronously to particular instructional materials. Agent behaviors are sensitive to both the educational context and to the history of student behavior.

30 In a preferred embodiment of this invention the agent integrates data from several sources. From computer-assisted instructional materials, it accepts data on the methods of instruction adopted by particular materials and on student performance in the instruction. From the student, it accepts
35 direct interactions as well as using the history of previous student performance stored in a student data object. From the teacher, it accepts data on customization and student

assignments. From the school, it accepts data on assigned courses, data on analysis of student body performance, and educational standards and criteria. In a preferred embodiment, these inputs allow individualization of agent interaction. Alternative embodiments are responsive to additional data types and sources.

In a preferred embodiment of this invention, diverse agent behaviors are handled uniformly by a single means. The diverse behaviors include encouragement and feedback, providing meta-cognitive help on ongoing instruction, managing or controlling and individualizing computer based instruction to the student's learning modes, and assistance with assignment management. These diverse behaviors are selected from a set of potentially appropriate candidate behaviors. This set of candidate behaviors is ordered and the highest ranked behaviors are chosen.

In a preferred embodiment of this invention the diverse agent behaviors adapt to the student based on a variety of information about the student. The agent modifies its behavior on the basis of a growing history of interactions with the student over time, as this history of student performance is stored in the student data object. The agent can also modify its behavior on the basis of teacher and school system supplied information.

Further, in this preferred embodiment, the student data object resides on portable media in the physical control of the student. This is advantageous because the student data object accumulates data personal to the student, and its privacy can be ensured by such student control. Alternatively, the student data object can be stored on central server computers in secure databases when this is advantageous to ensure student data privacy.

Another important object of this invention is that the agent presents itself on-screen to the student with integrated, and optionally, animated multimedia persona, or preferably a plurality of persona (hereinafter called "personae"). The on-screen agent can appear as living

entities, which in grade school can be comfortable "Study Buddies" and in adult training can be appear as an objective "Concept Coach". The on-screen agent instructs, motivates, engages and guides its student.

5 In a preferred embodiment, the on-screen agent can be dramatized by a single character or by a cast of interacting characters. The interaction between these actors can be individualized to reflect the pedagogical response of the agent. To maintain student interest in the agent response,
10 story lines continuing across materials or session can be used.

In a preferred embodiment of this invention the voices, gestures and motions of the personae are derived from the chosen behaviors, student personae preferences, and the
15 history of recent behavior by selection from tables containing a rich variety of alternative sound and visual display objects. All elements of the on-screen agent display are then synthesized in an integrated display script calling for graphics, animation, video, or sound as appropriate.
20 These scripts are then bundled into applets, run-time program fragments that represent a complete element of performance. This display is highly configurable by the student, the teacher, or the system administrator.

It is an advantage of this invention that elements of
25 the display objects can be created by artists, animators, singers, and so forth, as data snips. Pluralities of data snips can be stored in libraries of dynamic clip art and then installed in an implementation of this invention. In this manner the on-screen agent personae have an appropriately
30 contemporary, realistic, and engaging manner. Data snips are, in general, short clips of sound, voice, graphics, animation or video, or combinations of these used to construct the on-screen agent. A data snip can also be a complete pre-formatted animated sequence, perhaps in the
35 format of a talking animated daily cartoon strip.

Another important object of this invention is that the interactive, adaptive, and self-paced computer-assisted

instruction and homework provided by this invention is available to geographically dispersed students and from geographically dispersed schools or education providers. Accordingly, the system of this invention is adapted to both
5 the student data object stored on portable media and to the access of other important data across a variety of networks. For example, an implementation of this invention as a "HomeWork Network™" can make computer assisted homework available to students of all levels at home. In addition to
10 computers located at residences of students, the student can also access homework materials at computers located in youth centers, libraries, schools and other locations. A student only has to access a networked computer and "plug in" the portable student data object to receive instruction.
15 Alternatively, the student can access the student data object across such a network.

In a preferred embodiment, the network on which this invention is implemented as an intranet configured of appropriate links and utilizing the known TCP/IP protocol
20 suite, and as appropriate, ATM technologies, including World Wide Web, associated browsers, and mail format extensions. Implementation over the public Internet is equally preferred in cases where extensive connectivity is needed.

A further important object of this invention is to
25 utilize augmented computer-assisted instruction materials which present to students a variety of interactive, adaptive, and self-paced computer-assisted instruction and homework materials in a manner which informs the agent of a student's progress and performance and which permits the agent to
30 manage or control the materials to the student's pedagogic characteristics. Thereby, the ABI system can effectively guide and engage students in their educational tasks.

In a preferred embodiment, these instructional and homework materials are composed of materials data presented
35 by a materials engine. The materials data includes display objects containing the substance of the instruction, logic to sequence the display according to student input, and

notations. Notations are augmented definitions that serve to pass information to the agent concerning the materials and the student. For example, notations classify key sections of materials which are educationally significant student
5 actions. Preferably, authoring tools assist in developing these augmented instructional materials. Materials tasks and sequences are created and entered by instructional designers and subject experts. Notations are usually entered by instructional designers and can be customized by teachers.
10 In a preferred embodiment, the information passed in the notations is standardized according to an instruction materials interface standard. This standard establishes a uniform way the materials independent data relating to student performance are to be provided to the agent and a
15 uniform way for the agent to guide the student in a materials independent manner.

A further important object of this invention is to provide to the student a range of tools which are integrated with the agent in a manner similar to the instructional
20 materials. These tools include general tools helpful to assigned instructional tasks, and special tools for group work and communication and for student scheduling.

In a preferred embodiment, the general tools include at least a calculator, an encyclopedia, a dictionary, a
25 thesaurus, each appropriate to the several levels of students, which can access an ABI implementation. In a preferred embodiment, the group work and communication materials allow, when permitted, message exchange, student linking into groups for joint work, and student linking into
30 groups for structured work such as contests. In a preferred embodiment the student scheduling tool records assigned student activities and their priorities. In an embodiment, this tool can be consulted by the student to view schedules. It can be consulted by the system to prescriptively schedule
35 required activities, to permit student choice, or to permit a mixed scheduling initiative. Finally, it can be consulted by

the agent to offer scheduling advice to the student. Typically, student assignments are set by a teacher.

An object of this invention is reporting of student performance to students, teachers, parents, administration, 5 or to other appropriate individuals in a business enterprise or other commercial versions. These reports include the unique data on the student's pedagogic performance accumulated and analyzed by the agent, as well as all the usual and expected performance data on specific materials 10 available in existing computer-assisted instruction systems. In a preferred embodiment, data for such reports, called herein school-student data, is forwarded by the agent pursuant to school policies to school server computers from the students' local computer. On the server computers, it is 15 stored in server databases against which are run such reports. Alternatively, this data can be forwarded to existing student information systems present at the school. In a further alternative embodiment wherein the student data objects are centrally stored, this data can be derived from 20 these objects, which can be stored in an object oriented database system. It is an advantage of this invention in a school context that parents can have access to current data on their children, and thereby play a more informed role in their children's education.

25 Another object of the invention is to utilize current technologies for student interaction. When available, this invention is adaptable to Network Computers ("NC"). NCs are low cost computers specifically designed to access intranets or the public Internet. In a current preferred embodiment 30 and implementation, this invention is adaptable to multimedia PCs for some students, and to such special interaction technologies as can be advantageous to special students or students with special needs. Typical interactive devices include keyboards, mice or other pointing devices, voice 35 recognition, joy-sticks, touch activated devices, light-pens, and so forth. Other devices, such as virtual reality devices, can be added as they become commercialized.

It is clear to those of skill in the art that by providing interactive, adaptive, and self-paced computer-assisted instruction and homework delivered over widely available computer networks this invention has immediate
5 application in public, private, and commercial school environment of all levels. Educational research shows that instruction and homework of these characteristics improves students' educational outcomes. Further, in school contexts this invention advantageously provides immediate access to
10 student performance and pedagogic characteristics to all interested parties, including parents.

4. BRIEF DESCRIPTIONS OF THE DRAWINGS

These and other objects, features, and advantages of the
15 invention will become apparent to those of skill in the art in view of the accompanying drawings, detailed description, and appended claims, where:

Fig. 1 illustrates in overview fashion the principal functional components of and parties in the ABI system;

20 Figs. 2A and 2B illustrate in overview fashion an implementation of the functional components of Fig. 1;

Fig. 3 illustrates an exemplary student display screen of the implementation of Fig. 2;

Fig. 4 illustrates in more detail exemplary screen
25 interaction between the on-screen agent and the instructional materials of the implementation of Fig. 2;

Fig. 5 illustrates an exemplary interaction of a student with the ABI system implementation of Fig. 2;

Fig. 6 illustrates in more detail the software
30 components and hierarchy in the implementation of Fig. 2;

Fig. 7 illustrates exemplary message flow through the implementation of Fig. 2;

Fig. 8 illustrates agent action processing of Fig. 7 in more detail;

35 Fig. 9 illustrates agent behavior processing of Fig. 7 in more detail;

Figs. 10A and 10B illustrate the structure of student data object of Fig. 7 in more detail;

Fig. 11 illustrates exemplary processing of the student data object of Fig. 7;

5 Fig. 12 illustrates an exemplary sequence of student meta-requests and agent meta-responses.

5. DETAILED DESCRIPTION OF THE INVENTION

Sec. 5.1 presents a general overview of the Agent Based
10 Instruction system. Sec. 5.2 describes the preferred hardware and operating software configurations. Sec. 5.3 describes details of the instructional interface between the ABI system and its users. Sec. 5.4 describes in a general fashion the software structure of the ABI system with
15 subsequent sections describing each component in a more detailed fashion. Sec. 5.5 describes the instructional materials and the tools in a more detailed fashion and Sec. 5.6 describes the agent in a more detailed fashion. Sec 5.6 includes detailed description of the preferred interface
20 between the agent and the materials in the ABI system.

5.1. ABI System Overview

In the following, the systems and methods of this invention are described in the context of a school system,
25 with examples drawn primarily from elementary education. This invention is not so limited. It will be apparent to one of skill in the relevant arts that this invention can be applied at all levels of public and private education, from pre-school through university, and to all forms of commercial
30 or corporate education. In all these contexts, this invention has particular utility in making education and training available at school, at the office, at home, at schools with geographically dispersed students and to students at geographically dispersed schools, and at other
35 types of locations. Further, it will be apparent that this invention can be applied in contexts other than education

where monitored interactivity and individualization are to be provided, as in child care or weight loss.

The following glossary contains several terms frequently used in the Detailed Description of the invention. It is presented here as an aid in order to initially introduce important terms that are more fully described and explained in the following sections.

Agent: agent software together with the data it references
10 executing in an ABI system.

Agent Based Instruction ("ABI") System: the novel instructional system of this invention, preferably comprising an agent for responsive, adaptive and
15 individualized instruction of students and a network for distribution of instruction, which projects the personae of the virtual tutor.

Agent Software: software modules that generate responsive, adaptive, and individualized behavior in the ABI system, preferably implemented according to methods from
20 artificial intelligence.

Applet: an executable program fragment advantageously downloaded to a client across the network, in the ABI system applets are particularly used to represent a complete element of on-screen agent actions, or performance, (e.g., a character scratching its head and saying an utterance) and can reference various data
25 snips of animation, sound, and scripting information.
30

Authoring Tools: programs used by instructional designers to develop materials data, such development includes inserting notations.
35

Cast: a plurality of persona ("personae") representing the on-screen agent.

Character: an individual persona in the cast of the on-screen agent.

5 Concept Coach: a possible alternative name for a persona in the cast of an on-screen agent that is suitable for high school and adult students.

Data Snip: an elementary piece of sound, voice, animation, video, or a graphic; data snips can be combined,
10 preferably by an applet, to represent a complete element of on-screen agent action.

Electronic Learning Friend ("ELF"): a generic name for any persona in the cast of an on-screen agent; also a
15 possible alternative name for a persona suitable for middle school students.

Instructional Materials: the components of a course of instruction, such components are selected according to
20 the course and can include prerequisite tests, pre-tests, lessons, and unit tests.

Materials Data: the content of instructional materials.

25 Materials Engine: software modules that reference instructional materials data and tools data to present the instruction and the tools to the student.

Meta-request: a student request directly to the on-screen
30 agent, an exemplary request is 'asking for a hint.'

Meta-response: all responses to a student produced by the agent software, as distinguished from presentations by instructional materials, tools and communications.
35

Network: the hardware and software connecting student client computers to school servers in an ABI system; the

network connections can comprise fiber optic links, wired links, or terrestrial or satellite wireless links.

- Notations: interface information inserted into materials data that causes the materials engine to send and receive messages from the agent software; preferably notations create standardized interface messages between the agent and the materials.
- 5
- 10 On-screen Agent: presentation by the agent software on the student's display using such media as sound, voice, graphics, animation, video, or other multimedia modality; this presentation preferably displays one or more life-like personae.
- 15
- Persona: a character in the cast of an on-screen agent.
- Personae: the collective plural of persona.
- 20 School-student Data: data about each student's educational progress collected centrally; this data is forwarded by the student's agent pursuant to school data collection and privacy policies; depending on these policies, such data can range from none to essentially the entire
- 25 content of the student data object.
- Student Data Object: data about each student which the agent software references in order to provide responsive, adaptive, and individualized instruction to that
- 30 student; this data is updated during course of each lesson and is advantageously stored as one object, or alternatively a few linked objects, on portable media or in the ABI system.
- 35 Study Buddies™: a possible alternative name for personae in the cast of an on-screen agent that is suitable for elementary school students.

Tools Data: the content of tools supporting particular instructional materials; tools can include a dictionary a calculator, or an encyclopedia; and so forth, and tools data are the content of the dictionary, the calculator, or the encyclopedia.

Utterance: a text or voiced response by on-screen agent.

Virtual Tutor: the ABI system components acting together to emulate a human tutor; from an individual student's perspective, the Study Buddies™, ELF, or Concept Coach appears as his or her personal tutor.

The following sections of the Detailed Description elaborate each of these terms and describe their connection and interaction so that the ABI system presents responsive, adaptive, and individualized instruction and assumes the form of a virtual tutor.

5.1.1. Functional Components

In view of these objects and advantages, Fig. 1 illustrates the principal actors and the principal functional components in an ABI System. These include, generally, materials engine 102, agent software 108, and student data object 109, all of which interact with student 101 and with teachers and administrators 106 via a computer network described below in conjunction with Fig. 2 to create a virtual tutor of student 101. Student 101 is typically one of many students enrolled in a school or similar institution. Central to the ABI System is the virtual tutor individualized to each student, which formed by the functioning of agent software 108 with student data object 109, which stores characteristics of student 101 and assignments and standards set by teachers and administrators 106. Other actors not shown in Fig. 1 can be relevant in particular applications, for example, parents in the case of primary and secondary education.

Materials engine 102 presents educational content such as instructional units, homework assignments, and testing to student 101. The educational content includes instructional materials data 114, communications materials data 104, and 5 tools data 115. instructional materials data 114 include computer based instructional materials similar to those known in the art but, importantly, augmented with notations for use in this invention. The materials also include various tools 115 appropriate to particular instructional materials, such 10 as a calculator for mathematics, a dictionary for writing, access to on-line reference sources for research, and so forth. Further, materials can also include communication materials data 104, which define and provide communication with other students 105 for instructional purposes. Such 15 purposes can provide, for example, the tutoring of one student by another more advanced student, joint work of several students on one instructional materials lesson as permitted, and educational contests, such as spelling bees. Further, this invention is equally adaptable to other forms 20 of materials that function in the framework of Fig. 1, in particular interfacing to the agent software as indicated by arrow 111, and that are useful in a particular application of this invention. For example, materials appropriate for child care contexts can differ from the above three classes by, 25 perhaps, having different paradigms of interactivity.

The structure and course of interactions 103 between the student and the materials is preferably governed by paradigms of educational psychology and sound educational practice, such as are described in the exemplary reference Englemann et 30 al., 1982, Theory of instruction: principles and applications, New York: Irvington Publisher. At the most immediate level, for example, during homework or instruction, student 101 can make requests and receives responses from materials engine 102 and, in turn, materials engine 102 can 35 make requests and receive responses from student 101. The materials engine can adjust its sequence of presentation in response to student responses. At a next level, the requests

and responses exchanged between the student and the materials engine can follow several patterns known in the arts of computer based instruction and which, for example, include the following. First, the student can respond to questions 5 presented by the materials engine, and in the course of responding, can ask for advice or hints, the use of a tool such as a calculator, or other relevant assistance. Second, the student can advance to the next item, lesson, or unit upon successful completion of the present item, lesson, or 10 unit. Third, in case of error, the student can request, or automatically be presented with, appropriate repeat, review, or remediation materials. Finally, at a higher level these patterns of interactions can be analyzed to provide more adaptive responses from the system.

15 Teachers and administrators 106 also interact with materials engine 102 for several purposes, as represented by arrow 107. For example, teachers can customize existing materials by adding additional items, modifying existing items, altering the order of item presentation, changing the 20 notations (see *infra.*) governing agent interaction, and so forth. A teacher can create particular instances of materials suitable for one class, a group, or even one student. Further, although reporting of student progress preferably occurs by other means, in alternative embodiments 25 the materials engine can directly report student progress to teachers and administrators. For example, this can be done by entering notations that generate messages for the teachers.

Also, instructional designers can create, or "author," 30 materials for use in this invention. Such materials can be original or can be derived from existing textbooks, workbooks or media material. They can employ standardized curricula, pretests such as criterion tests, post-tests, and standardized texts. Authoring instructional materials in a 35 course suitable for interactive instruction typically comprises several steps, including decisions about the objects to display to the student, the sequencing of these

objects, and the interactions with the agent. The first step is the selection of objects which carry the education content for presentation to a student. Objects can include visual display items, such as text, graphics, animation or movies, 5 audible display items, such as voice, audio and so forth. They can include input items known in the computer arts, such as buttons to select, selections to chose from, text to enter, hypertext and hypermedia links, functions to perform with student input, and so forth. The second step is the 10 selection of the sequencing logic for the ordered display of the objects to the student and the educationally appropriate reaction to student requests and responses. The sequencing logic can reference instructional controls set by agent software 108, such as a command to increase example density, 15 and preferably is chosen in light of principles of educational psychology and practice as detailed above. The third step is the specification of interactions with a student's agent or virtual tutor, a key component of the ABI system. This specification is made by augmenting the 20 sequencing logic with "notations," which are referenced, called, or executed by the sequencing logic during object presentation and that communicate with the agent, in a preferred embodiment by exchanging messages. In the ABI system, the agent builds an adaptive model of its student's 25 pedagogic characteristics, in other words the student's cognitive styles, by monitoring the course of the student's interactive instruction. The notations are the means for this monitoring. Finally, in order to make materials available, the authored materials are indexed and stored in 30 the files of the ABI system, preferably on materials server systems.

ABI authoring tools differ from authoring conventional instructional materials in that notations are present in these materials to enable the agent software to update the 35 student data object, to monitor and modify the instruction, student's use of a tool, or a communication task. ABI

authoring tools support and facilitate the conversion of existing materials to the ABI instructional format.

As indicated above, an agent unique to each student 101 is important in the ABI system. A student's agent is comprised of agent software 108 in conjunction with a student data object 109 unique to each student. As the agent software monitors its student's instruction, it builds an adaptive model of its student in student data object 109. Guided by this model, agent software 108 acts, first, to manage or control the student's instruction, and second, to directly guide the student in order that the total ABI system can present education to each student in an optimal fashion best adapted to the student's evolving abilities, skills, and preferences. In other words, the agent becomes a virtual tutor by acting as a student's personal and individualized tutor. First, the agent manages or controls instruction of student 101 by directly controlling materials engine 102 in its presentation of materials data 104, 114, and 115 through interaction with the materials engine, as represented by arrow 111. The agent preferably manages or controls the materials engine in two manners, synchronous with materials data presentation, such as when the materials engine encounters an appropriate notation in the data, makes an agent request, and waits for an agent response, and asynchronous with the presentation, such as when the agent software adjusts control parameters which the materials engine references at decision points. Examples of synchronous control are an instructional material asking the agent for permission to allow the student to use a tool, to receive a hint, or to be given remediation, or a communications material asking the agent for permission to permit the student to engage in a particular type of communication with certain other students. An example of asynchronous control is the agent setting of pedagogic parameters, such as coaching parameters that the materials engine uses to adjust its presentation, according to the pedagogic characteristics of the student. Exemplary coaching

parameters include the time pacing of exercises, the new concept seeding rate and the density of examples. In this manner, the materials can present interactive instruction according to optimal values of the pedagogic characteristics or cognitive styles of each student as determined from the agent's observation of its student.

Second, agent software 108 directly guides the student by exchanging communication with the student, as represented by arrow 112. Student communication also preferably occurs in two manners, synchronously, in which the student directly makes meta-requests of the agent tutor and receives meta-responses and second, asynchronously, in which the agent tutor itself generates a meta-response in response to some instructional event. Herein, requests and responses are prefixed with "meta" when they are exchanged directly with the agent. Meta-requests include student questions to the agent - for example: How am I doing? What should I do next? Could you say that another way? - or student requests - for example: I need a hint; I need help. The agent responds to each student question or request. Agent meta-responses can be generated, for example, when the student takes too long to complete an exercise, when the student makes a series of repeated errors, or when the student achieves good performance. Agent meta-responses can be drawn from such categories as reminders, encouragements, reinforcements, paraphrases, jokes, progress summaries, and so forth.

Communication with the agent, represented by arrow 112, include direct student meta-requests that generate agent meta-responses. Other communications derive from instructional event messages generated and communicated by augmented notations in materials 104, 114, and 115. An event received by the agent can generate no meta-response at all or alternatively can generate an asynchronous type agent meta-response. At educationally significant points, as the materials sequencing logic presents display objects to the student and receives inputs from the student, the materials data author places one or more notations. When these

notation are referenced, called, or executed, important variables and parameters educationally relevant at this significant point are gathered into a message, along with an indication of the type of the educational event. These 5 messages are events which are then sent to the agent. For example, an educationally significant point is the beginning of a new instructional sequence. The corresponding event message can include an indication of the topic to be covered, the expected level of difficulty, the expected time to 10 complete, and the educational paradigm adopted. Another educationally significant point is the receipt of a wrong answer. In response, the materials can generate several messages: a first message can include the time required to make the answer, an indication of the type of error, and an 15 indication of whether the answer is completely wrong or only a near miss; a second message can include text parameters ("say-it" type message) if the agent chooses to make a specific text or spoken comment about the error; finally, a third message can include the screen location best 20 representing the error ("point-it" type message) to use if the on-screen agent chooses to point to the error or move to the location of the error. Another educationally significant point can be a long delay in receiving the next student input, at which point the materials engine can send an 25 asynchronous message indicating the time elapsed. Tools data 115 generate events similar to messages from instructional materials. Communications materials 104 can generate events recording a communication request or an initiation of communication with certain other students for a certain task. 30 In the case of shared work on one materials, communications materials can generate events recording how this student in progressing with the shared materials; in the case of a contest such as a spelling bee, events recording how this student is progressing in the contest with respect to other 35 contestants.

In addition, in a preferred embodiment agent software 108 also receives messages describing the progress of the

student through specific instructional materials. For example, in the case of mathematics materials, such messages can include information that the student is making errors in problems requiring finding common denominators. These event
5 message should preferably all information that can be of interest to teachers and administrators for tracking student progress and tracking course adequacy.

It is important that communication between the student and the agent be engaging. Agent communication preferably
10 utilizes all the modalities of input and output available in a particular implementation of this invention, including text, audio displays such as voice and sound, and video displays such as graphics, animation, and realistic movie clips. For example, in the case of a communication triggered
15 by good performance, the agent can select the display of sound and video clips, from a data snips library, that the student finds pleasing. The agent can further make reward graphics available on the student's screen for a period of time. On the other hand, in the case of error the agent can
20 point to the screen location of the error.

Further, it is highly preferable that the on-screen agent can assume various display personae during student communication. Herein, persona means the effect conveyed to the student of the combined and coherent presentation of
25 multiple display modalities to emulate a particular, apparently living, personality. For example, in the case of elementary education, this can be the selection of tone and animation to emulate a pleasant animal or a known cartoon character. In some cases, characteristics of the display
30 persona can be selectable by the student according to the student's preferences. In other cases, the personae can be specified by the instructional materials, the teacher or the administrator overriding student persona preferences. Personae for an elementary school student can be selected
35 from well-known cartoon characters and can perhaps be called "Study Buddies™." Persona for commercial or corporate education can be adapted to the organizational ethos and can

perhaps be called a "Concept Coach." Presentations for intermediate levels can be called an Electronic Learning Friend ("ELF"). Even though the ABI system through its network, software and database acts as the student's virtual
5 tutor, from the elementary school students point of view, the "Study Buddies™" are his/her personal tutor. Realism in voice, gestures and movement reinforce this relationship.

Agent software 108 in the ABI system builds an adapting pedagogic or cognitive model of its student in student data
10 object 109. This model is independent of specific materials. Event messages to the agent software from the materials engine preferably include the information from which this model is built. In general, event messages must include such content as is necessary to describe and parametrize the
15 pedagogic or cognitive style models adopted by the materials in an implementation of the ABI system.

In a preferred embodiment, the student data object 109 includes such data about a student necessary to the agent's evolving pedagogic or cognitive student model. Further, it
20 preferably also includes data concerning the student's current state and recent performance in the instructional materials being presented to the student. This latter data is interpretable by both the agent and the instructional materials. Finally, the student data object can include
25 private scratch-pad areas for the sole use of instructional materials. Data in the student data object is available for access during student sessions and is safely stored between sessions.

The student data object is preferably securely stored on
30 portable media in the physical control of the student. A student "plugs-in" such a portable student data object stored on portable media as part of accessing an ABI system. Preferably, this portable medium is a smart card, or similar device, which securely couples portable storage and
35 processing in order to shield the actual data and, instead, present a message-based interface to the student data object. Alternatively, the student data object can be centrally

stored on school computers and downloaded to the student's computer when the student access an ABI system. In this case, the student data objects are preferably stored in an object oriented database, although this data can be

5 advantageously stored in standard relational databases. As depicted by arrow 110, the student data object is referenced by the agent in order to generate its actions and is updated by the agent as it processes events and student meta-requests.

10 Especially in the primary and secondary school context, the school can need to gather educational progress data pursuant to its data-gathering and privacy policies. In cases where no single school is present, as in the case of multiple, dispersed education providers, no such school-
15 student data is generated by the agent. However, such school-student data 116, when present, can be forwarded to central school computers by agent 108. Also, school-student data can contain guidance to the student's agent, such as the school schedule. Accordingly, school-student data is
20 accessed not only by the agent software 108, but also by teachers and administrators 106. As depicted by arrow 113, school-student data is referenced by teachers and administrators in order to track the student progress and to generate reports concerning the students and the materials in
25 the ABI system. Teachers also update the school-student data to enter schedule information for the student's assignments, which can be referenced and used by the student's agent. Administrators update this data in order to enter the courses and materials the student must master and specify standards
30 and criteria the student must meet.

In an alternative embodiment, however, these various data can be combined. Student data object 109, whether portable or centrally stored, can contain both pedagogic and cognitive model data and educational progress data, the
35 school-student data 116. Such a combination is particularly advantageous in the case of central storage of the student data object.

5.1.2. Exemplary Implementing Structure

Figs. 2A and 2B illustrate an exemplary preferred structure implementing the principal conceptual and functional components of the ABI system as illustrated in Fig. 1. A preferred implementation of this invention is based on a plurality of computers interconnected by a network and, preferably, a plurality of portable storage media for the student data objects. Preferably, although all system functions can be performed on all interconnected computers, certain computers are specialized for certain functions, such as student client systems for providing student access or system servers for storing system software resources. Therefore, an exemplary preferred ABI system includes one or more student client systems 201, at which student 202 receives instructional presentations including homework. Other student clients are generally indicated at 203 and can be located at school, at home, or at the office. The system further includes one or more servers 204, at which teachers and administrators 205 gain access to the system. Alternatively, they can access the ABI system at their own client computer systems.

These components are interconnected by a network which consists of transmission medium 206 and local attachments 207. Although the network illustrated in Fig. 2A is of a bus-type configuration, as in a local area network perhaps using collision detection or token passing protocols or both, this invention is adaptable to all forms of networks which support adequate transmission protocols, such as those that are functionally similar to the TCP/IP protocol suite, and as appropriate, ATM technology. Thus, the invention is adaptable to networks constructed from switched or non-switched links to a central server, which can be configured of several LAN attached server systems, to networks including CATV cable or optical links, to networks including radio links either terrestrial or satellite, and to public or private packet switching networks. In the near future, for the majority of students, local attachment 207 is expected to

remain a lower speed access over the switched, public telephone network. In the more distant future, such lower speed local attachments may possibly be replaced by a higher speed access using currently developing high-bandwidth technologies.

A preferred public packet switching network to which this invention is adaptable is the Internet. ABI system nodes can be linked to the Internet in any convenient manner known to those skilled in the art and can include security boundaries (known as firewalls) to prevent unauthorized access. Alternatively, an ABI system implementation can be an "intranet," that is a network constructed according to TCP/IP protocols but using private links of the types enumerated above, and as appropriate, ATM technologies.

In more detail, student client system 201 includes memory 208, which is RAM type real memory or a virtual memory based on RAM type memory and a backing store. Preferably, to reduce size and cost, the client system has no permanent disk storage. When available, a preferable student client can be a low cost network computer ("NC"). A NC is a computer with processor, RAM, and network interfaces sufficient to access intranets or the Internet. A NC is preferable in cases when high-bandwidth network access is available. In cases of low-bandwidth network access, the client system can have one or more disc drives 209 which can be used as a pre-fetch buffer or a read-only cache. The disks preferably are magnetic, although in a less preferable embodiment they can also include CDROMs. This optional capability serves to enhance communications efficiency in cases where the network has relatively low bandwidth. Large files can be downloaded in advance of a student session or the student client can cache read-only data across sessions obviating the need for downloading such files. Such caching requires the operating system components to maintain some form of version control of the read-only data.

Preferably, an ABI system also includes portable storage media 240 storing a portable student object. Each student

has physical possession of such a media which contains the student data object for the student. The data on portable media 240 is accessed by client system 201 across an appropriate physical link 241. Advantageously, portable media 240 contains both storage and processing capabilities. The contained processing capability responds only to inquiry and update methods for data elements of the student data object; no methods or data need be loaded into RAM memory 224. Thereby, method execution is shielded from client system 201, and the actual data structures of the student data object are protected from accidental or malicious alteration or damage by any foreign software that might be on client system 201. In cases where adequate processing capabilities are present, such a portable media can implement many of methods of the student data object, appearing essentially as a "pluggable object." Illustrative such portable media can be a smart card or a PCMCIA card with flash RAM and a microprocessor. Such portable media also are more platform independent than are alternative media.

Alternatively, portable media 240 can be a portable hard disc packaged for access through a parallel or serial port of client system 201. The portable media can also be a standard floppy disc. In this alternative, student data object methods can be stored as executable modules and object data structures can be stored in a securely encrypted format to prevent unauthorized alteration of data values or data structures. Student data object access from such portable media begins with the loading and executing of appropriate executable methods by client system 201. These methods then fetch and decrypt requested data elements into RAM memory 224 for reference or for update. In this case, only the data is shielded from client system 201. This invention is adaptable to other portable media for the student data object, such as one portable client computer for, and in the possession of, one student which has that student's data object as a permanently mounted component.

Alternatively, in cases where portable media are deemed inappropriate, the student data object can be stored between student sessions on a server and downloaded when a student accesses an ABI system at a particular client.

- 5 According to all of these alternatives, a student can access ABI system services from any available client system at any time.

The student interacts with a client system using any appropriate interactive input/output ("I/O") modes 210. For
10 input, standard devices include pointing devices, such as mouse 211 or a track-ball, age appropriate keyboards, optionally speech recognition, and so forth. Speech recognition will permit brief conversations with the "Study Buddies™," or other personae, in limited areas. The
15 invention is adaptable to special input devices appropriate for particular groups, such as the handicapped, and to devices yet to be constructed. Virtual reality ("VR") interface devices such as VR gloves and VR display helmets can have immediate applications for special needs students.
20 For output, preferable devices include computer display 212, for displaying objects such as text, graphics, animation, and video, and audio output devices for voice and sound clips. The audio and voice can be constructed from data snips stored as digitized sound files in libraries. Alternatively, voice
25 can be synthesized from text. The invention is also adaptable to special output devices for special classes of students, e.g. the handicapped, and to new devices being developed.

Fig. 2A also shows an exemplary screen layout for a
30 student client that exemplifies the principal functions of this invention. The screen is preferably partitioned so that principal components of this invention are displayed; and important student actions are represented by icons or buttons. Thus, the screen includes materials and tools area
35 220 to the left, agent area 215 to the right, and a system toolbar 218, which includes a student customization area 221 at the top. The size of the screen partitions illustrated

preferably change from time to time in response to student customization or display requirements. In particular, either the materials area or the agent area can enlarge, perhaps up to the entire screen as needed. Materials area 220 is for the instructional materials, tools, and communication materials to present visual display objects and for these components to receive interactive input. This area is further subdivided into display region 213 and a materials specific toolbar 214. On-screen agent area 215 is for the on-screen agent to receive meta-requests and to display synchronous and asynchronous meta-responses. Also illustrated is an exemplary on-screen agent consisting of a single persona 216 and a meta-request icon 217. The persona can move to other screen areas as required. Both these components are illustrated as appropriate for elementary education. Other visual appearances would be appropriate in other situations. The system area at top includes toolbar 218 for selecting particular available system components. In particular, always available on this toolbar are selection icons 219 for the calendar and scheduling tool. Part 221 of the system area can be reserved for student customization, for example for the display of reward graphics "given" to the student by the agent or virtual tutor.

Functionally illustrated in Fig. 2A is an exemplary memory organization of a student client system when a session is in progress with materials being presented. Layer 222 comprises operating software and network communications. This software provides, among other services, support for I/O devices attached to the client, a file system with cache control, lower level network protocols, such as TCP/IP and ATM, and higher-level network protocols, such as HTTP V2.0.

Executive software layer 223 provides basic shared ABI system capabilities. The executive software verifies student identity and access authority, establishes communications sessions with the system servers as required during client start-up, downloads instructional materials scheduled for this student, and download executable software required from

the systems servers as-needed. In the preferred embodiment using portable media, the executive software verifies that the contained student data object belongs to the identified student and accesses the methods of the student data object upon request, primarily, from agent software 225. In an embodiment with centrally stored student data objects, the executive software downloads the identified student's data object from the student database. The instructional material and the software are read-only and are not changed during a session. The student model is updated by the agent during the student session and modified parts are stored back in portable media 240 or uploaded to the student database on a server. Such downloading can utilize higher level network transfer protocols, or alternatively, directly use lower level network protocols.

Fig. 2A illustrates that agent software 225, optional components of student data object 226, and certain instructional materials software 224 have already been downloaded. The materials are displaying objects in screen area 220, and as indicated by arrow 227 are forwarding events to the agent and receiving management or controls from the agent. The agent is displaying its persona(e) in screen area 215, interacting with the materials, as represented by arrow 227, and is referencing and updating data in student data model 226, as represented by arrow 228.

Arrow 228 represents different access methods depending on the embodiment of the student data object. In the case of preferred portable media with processing and storage, no components of the student data object are loaded in memory. Then, arrow 228 represents direct message exchanges, or method calls, to portable device 240 made across physical link 241. In the case of portable media such as hard disks or floppy disks, arrow 228 represents method calls to student data object methods loaded into memory 226. These methods can reference or load into memory additional necessary data components of the student data object. In the case of a downloaded student data object, arrow 228 merely represents

memory accesses to this data. Finally, in the preferred embodiment where the student data is separated into the student data object and into school-student data, arrow 228 further represents references and updates to such school-
5 student data, preferably on school servers. Such updates can include school-related educational progress data.

Finally, the student client system further includes standard components not shown, such as a microprocessor and input/output interfaces. Alternative implementations of the
10 student client system are within the scope of this invention. In particular, student client system function can reside on a server system. Further, the client system can be implemented as two machines, wherein a first machine performs substantially all the computations and a second machine is
15 for student interaction and sends student input and receives display instructions from the first machine.

The ABI system further includes one or more server systems 204 of Fig. 2B with sufficient large capacity discs
230 for storing all school-student data, all instructional
20 materials, and all software used in the system. Optionally, the servers can also store student data objects in an object-oriented database. The network is used to distribute software, instructional materials, and school-student data from these servers. In alternative embodiments, there can be
25 more than one server with software and data component storage divided as convenient across the servers. In a further and less preferred embodiment, the server can be a central host system. In comparison to the client systems, servers preferably have increased performance and higher speed
30 network connections 231 in order to make this stored data quickly available to the one or more student client systems. Access to school-student data allows teachers and administrators to track student performance by class, grade, subject, school and so forth.

35 Importantly, certain server systems can also perform a registry function. In cases where multiple schools or multiple education providers can be accessed by a student, it

is important to ensure integrity of that student's data object. In these cases, before allowing downloaded software to access the student data object, either indirectly through the agent, or, perhaps, directly, such software can be
5 validated as being both a correctly functioning component of an ABI system and a correctly identified component. In particular, the latter check prevents foreign software from masquerading as legitimate ABI system software. The information for these checks can be stored as a registry
10 function in certain common server systems. See, *infra.*, section 5.2.4.

The server systems are preferably configured as shown in Fig. 2B and are loaded with software 232 providing the following function. First, there is operating system,
15 network services, and file server layer 233. In addition to the functions of layer 222 in the client system, layer 233 also provides a file server facility including file backup and version control. System manger 234 includes facilities for access control, authenticating student access requests
20 and limiting file access to authorized users. For example, students can be limited to only their personal files; parents to their children's files and curricular related data; teachers to files and school-student data for their classes; while certain administrators have unlimited access. The
25 system manager can also maintain any necessary system logs. Instructional materials databases 240 and directories of executable software also reside on the server systems. When group communications is in use, agents and communication tasks monitoring the groups can reside on the servers. The
30 servers also contain areas 237 for administrative data and for reports and report software of interest to the administrative staff. The servers also contain teacher areas 238 for data and report software of interest to teachers.

Finally, the servers contain student database 235. This
35 database preferably includes school-student data, which is a source of reports for teachers and administrators and of data by which these staffs schedule student courses and

assignments. Preferably, student data objects, including data representing the pedagogic model of the student used by the agent software, are stored in portable media 240. In this embodiment, the servers preferably provide an area for
5 secure backup storage for these portable data objects. Optionally, student data objects can be stored in an object-oriented extension to student database 235.

Further, certain instructional materials can be made available specifically for the teaching staff, along with an
10 individualized teacher agent acting as a virtual tutor for the teachers. The facilities of the ABI system can be used to simplify teacher familiarization and system training. For example, such teacher training can be user instruction in the ABI system itself, or can be teacher versions of student
15 materials designed to assist the teacher in his/her use and customization (in the nature of today's teacher versions of textbooks). Further, there can be teacher specific tools, for example, to assist in generating student reports and class management. In this case the server system contains
20 special instructional materials for performing this instruction. Associated teacher data objects are implemented and stored similarly to student data objects. Client systems for teacher access have agents unique to individual teachers.

Alternatively, the flexible server structure of the
25 system permits administrative and teaching staff to perform their specific tasks on any computer system with enough computing resources to support these tasks. As for student access, necessary system components are downloaded from servers to these temporary client systems. Thereby, these
30 personnel are not limited to sessions on server systems. Further, materials authoring can be done on server systems, client systems, or on separate systems not interconnected with a given ABI system. To make authored materials available, they are transferred to and indexed in the
35 appropriate server system databases.

Alternative implementations of the functions described for the student client systems and the server systems are

also within the scope of this invention. For example, it is known to those of skill in the art that by the use of various technologies, such as remote procedure calls or messaging, the functions pictured here as grouped together and on one system can be divided and distributed if needed.

5.2. System Hardware and Operating Software

The system elements illustrated in Figs. 2A and 2B can be constructed on standard hardware platforms meeting the requirements discussed in this section.

5.2.1. The ABI System Network

It is important that students or teachers be able to access an ABI system from any adequate client system anywhere at the school, at home, and when away from home, as in distance learning. Portable student data objects and networks permit students and teachers to participate at more than one school, and, further, permit delivery of homework and instruction to remote locations. In each case the client system must access instructional materials and ABI software from the network.

In various embodiments, a student can access one ABI system, as might be the case for a student enrolled at one elementary school. Alternatively, a student can have access to multiple ABI systems or multiple providers of ABI-system compliant instructional materials.

Access to all system components is typically provided from ABI system servers attached to the network. Preferably read-only software and read-only instructional materials are provided from server systems. The advantages over local storage of these elements at client systems include simplification of version control and of access control. The student is freed from insuring the client system accessed has all the necessary software and manually transferring if not. Also server storage provides greatly reduced client system storage requirements, in view of the large amount of software and instructional materials in ABI systems. However, in

systems with limited communication bandwidth, it can be preferable to cache recently used software and instructional materials in order to shorten response times.

Networks suitable for an ABI system can be of any configuration and protocol that meets the system's client-server communication and object transfer requirements, where the client is either a PC or a network computer ("NC"). Suitable networks can be private or public. The preferred ABI network in the case of PC clients, according to current technologies, is an intranet running the TCP/IP protocol suite and utilizing ATM technologies as appropriate. In one implementation, utilizing a single large server, such a server can be directly connected to the intranet or Internet. In another implementation, utilizing several smaller servers, these servers can be connected into a cluster by a LAN, preferably an Ethernet LAN. In this case, the ABI network is built from a local Ethernet LAN with remote connections to telephone lines using 28.8 Kbps modems, or other network links. In an alternate implementation, the network can be visible to the public Internet if adequate security systems (firewalls) prevent unauthorized access. This can make wider access available at lower cost than by switched telephone remote connections.

The ABI LAN can be further connected to other ABI LAN's and to other networks, such as the Internet, by standard use of routers and gateways. An exemplary protocol for an ABI System network is TCP/IP supplemented with a client-server protocol such as HTTP and object transfer protocol, such as a multi-format mail protocol. ATM technologies are used as appropriate. Remote clients are expected to be indirectly connected to the ABI network. These connections can consist of routing over a public network or direct dial-in connections. These connections can be of either low-speed or high speed. The ABI system can be implemented on networks such as @Home (Mountain View, CA), which use a combination of ATM, cable modems, TCP/IP and other technologies. The ABI system can also be hierarchically configured on new network

topologies for distance learning in areas with limited communications infrastructure. Primary central servers with ABI software and instructional materials communicate with remote secondary servers over broadband satellite communication systems. Student clients connect to the local secondary servers through wired or wireless means.

5.2.2. The Client System

Considerations governing the choice of client hardware and operation software are described next and are followed by a preferred client node system according to today's technology. These consideration depend on the content of an ABI system and the facilities of technology. As the content of a system changes and as technology evolves these consideration dictate that the preferred system will change.

The client hardware consists of client input/output ("I/O"), client CPU and memory, and client network access. Turning to the client I/O requirement, standard input devices such as keyboard and mouse, or other pointing device, are preferable. The client system also includes interfaces to a portable student data object. Such interface can alternatively include a smart card access device, PCMCIA ports, standard parallel or serial ports, or floppy disk drives. Color graphics output capability adequate to support partial screen animations is preferred. Sound generation and output are preferable on ABI client systems. Text-to-speech conversion can be done either in software or in hardware. When economically available, full video capability, for example by providing video decompression hardware such as MPEG decoders, and speech recognition, for example with hardware assists, are also preferable.

The ABI system is also adaptable to special I/O devices appropriate to special student groups, such as the very young or the handicapped. These include, for example, simplified keyboards, touch panels, VR devices, and so forth.

Client memory must be sufficient to contain resident operating system components, resident ABI executive software,

and dynamically loaded segments of the student data object, instructional materials, and code. High performance CPU's together with high performance graphics hardware and memory is preferable to enable more advanced presentation effects.

5 In embodiments where part or all of the ABI software is implemented in special languages, hardware or software assists for these language are preferable. For example, where such a special language is JAVA™ (Sun Microsystems, Mountain View, CA), JAVA™ chips, which enhance performance of
10 the JAVA™ interpreter, are preferable. The ABI client node in certain embodiments can be a JAVA™ enhanced network appliance adapted to Internet communication access and the HTTP V2.0, or equivalent client-server protocol.

It is preferable to eliminate the need for permanent
15 data storage devices, such as hard disc drives, by downloading all client software for each session. This allows the use of low cost 'network appliances' as student client computers. However, for those clients with lower speed network access asynchronous downloading can be used.
20 Storage devices such as hard drives can be preferable for pre-fetching or caching of read-only software components in order to reduce start up time. To download 4 megabytes of software using, for example, a 28.8 Kbps modem takes over 20 minutes. In the case of caching on student client, standard
25 version control methods known in the art are necessary to ensure that only up-to-date software and materials data are used. If an element is found to be out-of-date by querying a server, the current version is downloaded.

The portable media for the preferred embodiment of the
30 student data object includes devices with storage and processing capabilities, such as smart cards and PCMCIA cards with flash RAM and a microprocessor. Alternatively, portable hard or floppy drives as are commonly available can be used to store the student data object. Typically, this data
35 object, including accompanying access methods, is approximately 100 KB, and preferably less than approximately 1 MB. In the case in which the student data object is stored

on server computer, it is not be cached between sessions so that it can be accessed from other client systems.

Client communication hardware can be adapted for either local or remote attachment. Local access requires network
5 access hardware; remote access requires a communication capability. This invention is adaptable to lower speed access over switched telephone line services, preferably using 28.8 Kbps modems or ISDN interfaces (64 or 128 Kbps). These bandwidths are adequate for sessions with materials
10 using only voice and limited animations. Pre-fetching and caching can be required to make fullest use of other materials at this bandwidth. This invention is also adaptable to high speed access over any available high speed links, such as T1 (1.5 Mbps), T3, ADSL telephone lines, or
15 cable modems (several Mbps), or other means of high speed access. These bandwidths permit full access to materials without limitation. If economically available, high speed access is preferred. With greater communications bandwidth, the on-screen agent can appear more life-like.

20 Standard client software includes an operating system and communication software. The operating system preferably has interfaces to client I/O devices including communications capability and network access, such as a TCP/IP stack. ATM interfaces are present if necessary. Preferably, it also has
25 means for establishing sessions with servers, for providing file server services, and means for security as specified shortly.

The implementation language or languages of this invention preferably have several features related to the
30 implementability, maintainability, and extensibility of ABI. The implementation language preferably provides a degree of modularity similar to that provided by object-oriented programming languages. It preferably provides means of dynamically loading across a network and executing additional
35 software segments during program execution. It preferably provides means of accessing all input devices and of controlling the output devices in a high level display object

fashion. It preferably provides a threaded or multiprocessing capability. Less preferably, this invention can be implemented in any computer language, including assembly language.

5 In view of these needs and in view of the current technology, a currently preferred client system is a IBM type PC with a Pentium™ 120 Mhz processor, 16 MB memory, a 1 GB disk drive, a Soundblaster compatible sound card with speakers, a medium performance graphics card such as a
10 Diamond Stealth card with 2 MB of graphics memory, an Ethernet card or a communication card and a 28.8 Kbps modem, and standard keyboard and pointing device such as mouse. The operating system is Windows™ 95 with network services provided by a World Wide Web browser equivalent to Netscape
15 2.0 or better and capable of running Java™ applets. Java™ together with standard system and graphics classes is the implementation language.

5.2.3. The Server System

20 The functions of server systems of this invention include storage of databases of executable software elements, of school-student data, if any, and of instructional materials. Optionally, it can also store student data objects. The latter elements consist of heterogeneous and
25 structured elements. These elements can be stored in a relational database such as supplied by the Oracle Corp. or the Sybase Corp.; they can be stored as specialized data files; or they can be stored in an object-oriented database system such as ObjectStore (Object Design Inc., Burlington,
30 MA). The operating system of the server nodes must support whatever database systems are selected as well as network and application server software to access the databases. Application database server software of this invention preferably provides database access and version control and
35 downloads database elements on client request.

The preferred server hardware and software can vary widely depending on the number of clients to be

simultaneously served. This number can vary from 20 at one school to more than 5000 across an entire school system. The number of servers and database distribution across a server cluster can be adjusted by means known in the art to satisfy
5 projected peak loads. A suitable medium performance server system can be configured on a high end INTEL Pentium or DEC Alpha system with adequate memory and disk space. Windows™ NT is an adequate server operating system, and Internet server software similar to that from Netscape is adequate for
10 network access. The preferred database is an object oriented database such as ObjectStore. In this embodiment, application database access uses a common gateway interface ("CGI") program also providing database access and version control. The CGI access program can be implemented in C++, a
15 suitable object oriented programming language capable of accessing interfaces to ObjectStore databases.

5.2.4. ABI System Security

Security and access control present additional client,
20 server, and portable media requirements which are importantly part of an implementation of this invention. Security and access control can be maintained by careful selection of management policies, security software, and security hardware. These elements are described in this section in the
25 order of authorizing and controlling access, operating system and network security requirements, implementation language issues, and portable student data object security.

In a preferred embodiment, the primary means for authorizing and controlling access are passwords. System
30 management of passwords preferably includes ensuring that user passwords are secure, not easily guessed, and are periodically changed. This invention is also adaptable to any other means of access control, including for example, passive and active identification cards and recognition of
35 certain personal characteristics, such as voice. Access protection can be preferably provided by limiting access to system resources - database and file - based on a user's

password. For example, access protection can be implemented in the CGI application access programs.

The operating system in clients and servers of this invention is preferably of a tested security level. This base security can be enhanced by a variety of techniques and tools that can provide increased levels of security for additional investments. Such techniques and tools include firewall machines, that is dedicated network gateways that filter incoming and outgoing packets according to content criteria, and monitoring software, such as tripwires, that observe system events for suspicious combinations. Further, encryption can help protect sensitive and valuable data from illegitimate access by those without the key. Encryption in hardware and software can be provided according to methods known in the art, such as the Rivest-Shamir-Adelman (RSA) public key algorithm or the data encryption standard private key algorithm.

For those embodiments and materials data that download executable code segments, the implementation language importantly should address the security exposures thereby created. For example, a malevolent and knowledgeable user can create or modify the downloaded code to perform illegitimate operations within the client system or access restricted information from the server. The Java™ language is preferable in these embodiment because it now significantly addresses these problems and further improvements are constantly being made. Examples of Java™ security measures include limiting access to client system resources, particularly the file system and network connections, preventing downloaded software from "spoofing" local software, and providing byte-code verification to test code for possible security violations. Any implementation language for an ABI system preferably offers similar or improved security features.

Additionally, it is advantageous to protect a portable student data object from being altered in an unauthorized manner, corrupted, or damaged. When ABI system compliant

materials can be downloaded from multiple ABI systems or educational providers, particular care is advantageous to ensure correct functioning of these materials. Such student data object protection is accomplished by validating
5 downloaded software and by encryption and key management for the student data object.

Software validation includes registration procedures and runtime access control procedures. Before software or materials can be downloaded, they are preferably registered
10 with an ABI system registry function, which can reside on a network accessible ABI server system. Before registration, proposed software is formally or informally inspected to ensure that it is safe, that is that it does not cause illegal or undefined system states. As previously described,
15 a safety inspection is facilitated if the software is written in Java, which permits formal safeness checking. Also, the software is inspected to ensure that all modifications of the student data object are appropriate, that is that all modification reflect correct use of queried or updated
20 fields. Upon passing these inspections, software is given a system identifier and its executable or interpretable forms are given a digital stamp by a checksum or cryptographic hash function to insure its identity. The system identifier is stored in the registry along with the digital stamp.

25 At runtime, when the student requests access to particular ABI system compliant material or software from a provider, the student data object access control methods on the client system perform the following checking process. First, these procedures generate a request to the registry
30 function to verify the software to be downloaded by providing the registry with the software identification. If the server responds that this software is not registered or authorized, the download request is rejected. If this identifier is validly registered, the registry returns the digital stamp
35 associated with this identifier. The access control then downloads the software or material, recomputes the cryptographic hash function or checksum, and compares it with

the registered value. If they do not correspond, the download request is also rejected. If they correspond, the software is assumed to be safe and correctly identified, and the access control sets indicated access authorizations.

- 5 Such access authorization can limit this software to access only particular components of the student data object and with only read or read/update permissions.

Additionally, during access to the student data object, the access methods can consult rules so that clearly
10 incorrect patterns of access can be rejected. For example, a clearly excessive rate of parameter update can be caught and rejected.

In addition to software validation, procedures for access control, encryption, and key management of portable
15 student data objects are advantageous. As the portable student object is an important repository of agent knowledge, temporary instruction materials state data, and, optionally, educational progress data, it is important that it not be altered or corrupted accidentally or maliciously. To achieve
20 reasonable and effective protection, first, the portable student data object advantageously includes the student's password, or other identification means, in a protected form. When this object is plugged-in to a client system, a preliminary access control method insures that the student
25 has supplied correct identification to the client system.

Second, the student data object data is advantageously encrypted whenever it's data is present in a manner freely accessible by the client system. Therefore, in embodiments such as portable hard or floppy disks, the student data
30 object data is stored encrypted on the disk. Portions are decrypted in memory only in response to specific access methods. In embodiments, such as smart cards or PCMCIA cards with processing, which provide for method processing as well as data storage, the data can be internally stored in plain
35 text. However, when externalized, the data is encrypted. Such externalization is necessary in case student data object backup facilities are provided. For backup, internal data is

externalized as a encrypted, sequential, stream which can be stored and recovered from a backup system.

Such student data object encryption can be supported by key management schemes known in the art. For example, a public-private key scheme can be utilized. A student's public key can be stored on the ABI system which processes student system logon requests, and returned to the client upon student logon. The private key is stored in a protected manner in the portable student data object. Thereby, after student logon to the ABI system and validation by the portable data object, both keys are available to decrypt or encrypt data as required.

5.2.5. ABI System Usage Metering

Each student receiving ABI instruction on a specific topic is presented with a combination of instruction, utilities, and on-screen agent interaction. Because the ABI System provides individualized interactions, each such presentation comprises a unique mixture of visual, audio, and software elements. Also, each user's consumption of hardware and communications resources differs. The ABI System therefore preferably incorporates metering technology to track the utilization of the different elements of the ABI System. Such information can be used to determine payments to the creators or providers of these elements and/or as a basis of charges to the user. Further, this information can be used by ABI System providers to determine absolute and relative usage of various components of the system. Parties interested in such information include providers of server hardware, application software, networks, instructional and tool content, authoring tools and on-screen agent animations, scripts and utterances. Finally, this information can be used to monitor system performance and utilization.

Current metering technology does not provide the detailed measure of usage that is advantageous to ABI System providers. Such technology adapted for network distribution

of content is available from, e.g., the IBM Corporation, as the IBM Cryptolope, and Electronic Publishing Resources (EPR), as the Digibox.

The ABI system comprises hardware elements, standard
5 software elements, special application software elements, and content elements typically supplied by different providers. Hardware elements include networks and other communications links, server CPUs, and disks. Standard software elements include operating systems, database packages, and
10 communications software. Application software includes instructional playback engines, schedulers, and agent software. Content includes instructional materials, utilities such as dictionaries and encyclopedias, and on-screen agent animation and utterances.

15 ABI metering comprises the elements of the metering utility software, of tagging of all ABI component elements, and of the preferred methods of monitoring. The pricing and compensation model is preferably provided by system administrators. The ABI Metering Utility Software ("The
20 MUS") measures usage and maintains usage data in a 'multidimensional usage model' during each student session. The MUS is resident at run-time on the student clients and the system server(s). In the student client, the MUS is a component function of the Session Manager with inputs derived
25 from the Executive Software, Agent Software and the Materials Engine. In the Server system, MUS is a component function of the System Manager Software.

To facilitate metering, each ABI element is tagged with an ownership identification code similar to a product
30 barcode. The first digits indicate ownership and subsequent digits indicate the specific component. As the elements move through the system from server to client and within the client, the use of these elements is metered. In the client software, the Materials Engine uses materials ownership tags
35 to meter content. The agent utterance generation and visual display generation uses tags of the data snips to track

ownership of on-screen agent actions. The session and screen manager keeps track of which element of the screen is active.

This invention is adaptable to any method for measuring usage appropriate to the particular component elements. In particular, four preferred methods of measuring usage are by-time, by-interaction, by-unit and by-packets. The by-packet method is performed at each server to track usage of communications resources. This method is preferably implemented by using a count of the number of bytes transferred in order to estimate the number of packets transferred. The ABI application software keeps track of counting the number of bytes transmitted to the user according to content type (i.e. system packets, instructional materials, or elf animations). Then based on the network transfer protocol used, the byte count may be converted to a roughly equivalent packet count. Alternatively, the byte count may be used directly as a measure. In the case of multiple servers, each server sends a summary of packet transmission information to a unique metering utility server.

The by-elapsed-time method is performed at the client. In this method, the Screen Manager at the student client keeps track of the multiple simultaneous on-screen activities such as instructional materials, the elf, and the dictionary. This method preferably further monitors the active element of presentation, that is, the element performing an action or the focus for student input. In a more limited alternate implementation, the connect time of the student may simply be measured at the server. To avoid network problems such as lost connections and missed session signoffs, the System Manager application at the server additionally periodically obtains session statistics during a user session, either by polling the student client or from timed client downloads.

The by-units method is preferably implemented either at the server or at the client. This method measures the content accessed by the client. For example in the case of instructional materials, the server records the specific lesson accessed while the client records the completion of

exercises. In the case of on-screen agent actions, this method records each completed display or animation sequence or utterance.

The by-interaction method is preferably performed at the client and records both fine-grained interactions, such as clicks and keystrokes, and the medium grained interactions, such as completed responses and meta-requests. This method when combined with the by-time or by-units methods provides an indication of the relative level of interactivity of the instruction. For example, during use of instructional materials, the by-interaction methods measures the actual usage of each resource such as agent processing.

Usage of the different ABI elements is preferably metered by an appropriate method. The methods described above are not uniformly advantageous to different types of presentation. A graphics designer might seek compensation based on the amount of time a design is on the screen, while the instructional designer might seek compensation based on the fraction of the lesson completed. Accordingly, the by-elapsed-time method is preferred for graphics designers, while the by-units methods is preferably used to record the publisher and lesson for instructional materials, the type and author for tools material, and the creators of the animation and utterance for on-screen agent actions. The by-packet method is preferably used to record the source of the network traffic such as access to the student object database or downloading of application software, instructional materials, or animation data snips. The preferred metering methods provide information needed for the typical owner compensation and user pricing models.

In its preferred embodiment, system administrators provide pricing and compensation models. This invention is adaptable to many alternative such models. One user pricing model is a flat rate based on the type of instruction being made available, similar to pricing in the cable industry. Another is based on connect time, as frequently done for

Internet access, or on type and quantity of information retrieved, as is common for on-line database access.

TABLE 1A illustrates an exemplary model for compensating providers of ABI system elements. Compensation is based on metering data and an allocation model. The four metering methods are applied selectively to different providers. The allocation amounts 'a', 'b', 'c' and 'd' are externally determined.

10 **TABLE 1A: TYPICAL MODEL OR USING METERING INFORMATION**

	PROVIDERS	COMPENSATION FOR PROVIDER
	Billing/Network	'a' percent
15	Server Hardware Providers	'b1' percent divided up according to number of packets with up to 'b2' percent additional if total number of packets exceed a predetermined level
	Instructional Materials Providers	'c' percent divided up according to units
20	Calendar/Scheduler Provider	Up to 'd' percent based on level of interaction
	Animation Providers	'e' percent divided up according to 'time on screen'
	ABI Client/server Software Provider	Balance of revenue
25		

5.3. The Instructional Interface

The ABI system has interfaces for students, teachers, and administrative staff. Materials and software developers can have specific ABI system interfaces. Alternatively, such development can occur on separate systems followed by indexing and loading of the developed components into the appropriate databases.

35

5.3.1. Student-System Interface

This section describes the structure and design of the student-system interface. This description is directed to the currently preferred implementation of this interface by a series of visual display screens. However, this invention is not so limited, and adequate alternative technologies, for example voice output with speech-recognition input, can be used to implement this design.

10

5.3.1.1. Exemplary Student Screens

During materials presentation, a student sees screens of one or more screen types, all formatted in accordance with the previously described design principles. Screens are structured as a hierarchy of areas and subareas with text, graphical, animation, and perhaps video objects displayed in the subareas. Objects can either be for display only or permit student input or interaction.

An important screen type is a task screen. Task screens are used for materials presentation tasks such as homework assignments including problems, programmed steps, mastery quizzes, and drills. Table 1 and Fig. 3 illustrate exemplary components of a task screen appropriate for elementary education. Reference numbers in Table 1 are from Fig. 3. In general, in system area 302, the session manager presents objects visualized as icons permitting the student to easily access ABI system facilities. In materials area 304, object presentation including description, placement and movement, is specified by the materials designer in the presentational and sequencing sections of the materials data. The materials engine interprets these specification at run time to send display objects for display. In agent area 303, agent behavior processing formats predefined parametrizable objects, including resolution of object parameters, representing selected agent personae. The output from all selected and formatted display objects is sent to the executive software and operating system for ultimate display to a student.

TABLE 1: STUDENT SCREEN DISPLAY ELEMENTS

REF NO.	NAME OF ELEMENT	DISPLAY OUTPUT OBJECTS
	301 Screen	Entire ABI display area
5	302 --System Area	
	305 --Customizable	Graphics and text (can be animated)
	306 --File System	Book icons with titles
	309 --Scheduling Toolbar	
	307 --Monthly Calendar	Graphics
10	308 --Clock	Dynamic graphics
	310 --Toolbar	Icons of tools (for calculator, word processor, dictionary, communications, etc.)
	304 --Materials Area	
15	311 --Open Book	Graphics of book outline
	312 --Section Tabs	Graphics with text
	313 --Exercise Area	Text, graphics
	314 --Header	Text, graphics
	315 --Presentation	Text, graphics, animation, video
	316 --Input	Interactive objects (buttons, etc.), filling in text, dragging, drawing
20		
	321 --Navigation Buttons	Graphics
	317 --Student Action	Icons for Submit, Help
	309 --Sched./calendar	Graphics for calendar with text of student schedule, icons for scheduling options
25		
	303 --On-screen Agent Area	
	--Audio	Synthesis of spoken utterance
	318 --Text Message	Text utterance
30	319 --Visual Persona(e)	Appearance integrated with audio, graphics background effects
		Interaction with other screen areas
	320 --Agent Request	Agent meta-request icon, generates pull-down menu of meta-requests
35		

In more detail, the task screen of Fig. 3 includes in system area 302 student customization area 305. In the

customization area, the student can display objects given by the agent as rewards for student accomplishment. These objects can include text, as illustrated here, graphics, or animations. Another part of the system area is file system toolbar 306 displaying accessible files as icons in a "book-on-shelf" metaphor. This invention is adaptable to other reasonable file system display metaphors. Here, for example, the book icons represent a file personal to the student, a file holding ongoing instructional materials, a file of e-mail, and files for tools such as a dictionary and group activity. Below file system toolbar 306 is toolbar 310 for tools the student has access to. Illustrated here are icons for a calculator, a word processor, communications, and starfish, a general purpose language tool.

"Starfish" are a visualization tool for semantic networks that can be available in an ABI System. A semantic network typically consists of nodes linked to other nodes by semantically significant and named links. A starfish tool visualizes such a network for a student by displaying the node centrally in the body of the starfish with the node's links displayed as arms of the starfish. For example, a dictionary represented as a semantic network might include a node for each word with links to similar words, opposite words, root words, and so forth. A dictionary starfish displays a word in its body. Each selectable arm is labelled with a category - synonym, antonym, pronunciation and so forth. Clicking on an arm causes the corresponding word(s) to be displayed or spoken. Such a tool provides integrated display of diverse knowledge structures for a student.

The scheduling/calendar tool is an important tool that is always available. Exemplary icon 309 illustrated for this tool has calendar part 307 and clock part 308. Selection of each of these parts brings up daily and monthly scheduling functions. These function can either prescribe the student's next activity or permit choice where the student has excess time or demonstrated personal scheduling ability.

In materials area 304, instructional materials, tools, and communications materials display their content. Illustrated in Fig. 3 is page 3 of an exemplary mathematics homework. Instructional materials are advantageously
5 structured as a book of exercises and items, emulating current textbook and workbook practice. In this case, section tabs 312 permit the student to navigate the homework book by sections, and page buttons 321 permit the student to navigate the homework book by page. Also present is toolbar
10 317 of available student actions, which for homework includes submit and can, if the agent permits, include help and hint requests. The format of a materials page is advantageously standardized. An exemplary standardization has header information 314, presentation 315, and interactive input area
15 316.

On-screen Agent area 303 allows the student entry of meta-requests and allows the agent to display synchronous or asynchronous meta-responses. This exemplary area illustrated in Fig. 3 comprises meta-request button 320 which the student
20 can activate to display a list of currently available meta-requests. Student meta-requests are generally allowed by the ABI system at any time. Requests may occur at the beginning, middle or end of instructional sequences, in choice screens, in tools, in group communications, or in the calendar. Agent
25 meta-responses are individualized and context dependent. Typical meta-requests are illustrated in Table 1B. As an example of context dependence, if the request 'Where am I?' occurs within a lesson, a graphic representation of the lesson will be shown; whereas if the same request is made
30 between lessons, a graphical representation of previous lessons and new lessons will be shown. The agent software attempts to respond based on the user's intention and uses the context and previous requests to infer the reason for the current request.

35

TABLE 1B: TYPICAL META-REQUESTS

TYPE	META-REQUEST
5 Temporal: Time remaining in current unit/session/days work	'How far along?' 'How much longer?'
Marker: name and description of current lesson/exercise; relative position in lesson	'Where am I?'
10 Pause: Repeat of instructions: summary of what has been done	'Say it again.' 'Say that another way.'
Performance: summary of work in current lesson	'How am I doing?'
Choice: Branch to take. e.g. which lesson to do next	'What do I do next?'
15 Purpose: function of current lesson	'What is this for?'
Resources: assistance available at this point	'I need to hint.' 'I need help.'

The instructional materials notations provide a framework for the agent software to keep track of the relative position of the student in the lesson. This same information is also available to the teacher for lesson preview and annotation.

The remainder of area 303 is for agent meta-responses, which importantly have multi-media structured into personae. Illustrated are text message 318 and visual persona 319 that typically includes animation. Also possible is audio output, either text-to-speech or generated from audio files.

Fig. 4 further illustrates an exemplary screen interaction between the materials and the agent. Fig. 4 shows only the content of materials area 501 and on-screen agent area 502 of the complete display screen of Fig. 3. A mathematics homework material is displaying item presentation 503 with input selection buttons. The student has selected wrong input button 504. At this educationally significant event, the materials send to the agent several messages generated by notations in the materials data. In response, the student's agent has chosen to act as illustrated. First,

it displays text 506 of the rule violated by the student answer. This text was sent to the agent by the materials in an event message for its use. Second, the on-screen agent points 505 to the screen location of the error. This
5 location was also sent to the agent by the materials. Third, perhaps in response to a previous high or increasing error rate of the student, the on-screen agent presents a meta-response 508 commenting on the pedagogic nature of the student's error. Further, it activates a persona 507 to
10 engage the student's attention. This persona can advantageously include animation, audio, and speech output of the displayed text. Thus, the agent software integrates speech utterances, visualization, display of text and graphics, and animation into a persona display for
15 highlighting an educational event that the agent determined important based its processing of the current input, past student inputs in this lesson, and the student's pedagogic model generated over several sessions.

Other screen types are of importance in an ABI system.
20 For example, tools can have distinctive screen types appropriate to their nature, such as a calculator image. Choice screens can be used at the transitions between instructional sequences. They summarize what instructional materials have just been completed, announce status
25 information, and list any materials choices now available to the student. These choices can related to instructional materials to be undertaken next or to optional, non-instructional materials, such as exchanging credits for time in a game room, access to e-mail, and so forth, that can be
30 available to the student.

5.3.1.2. Student Actions

The inputs of a student or other user of the ABI System are preferably classified as requests, meta-requests, or
35 data. A student request is an input directed to materials or to the system seeking a specific action. Student data is an input responding to a system request for information. For

example, student requests include an input to the system to start the calculator is a request, or an input to certain materials to submit completed homework to the teacher. However, input of numbers into the calculator is data. This invention is adaptable to a further particular type of data input, termed semiotic, in which the student selects certain signs or symbols to provide input. Semiotic input is particularly advantageous when the agent requests the student to report his feeling or appreciation for a particular educational event. Meta-requests are inputs directed to the agent seeking specific actions. For example, student input to the agent seeking hints during the current materials is a meta-request.

Displays produced by this invention are preferably classified as applications, responses, meta-responses, or questions. Application display occurs upon system initiation of an available material, for example, an instructional material or a tool. Application display usually occurs in response to a student request, but can also occur on system initiative. For example, the agent can request the system to make a tool available to the student. Responses are all displays produced by materials or by the system. For example, responses include materials presentation display and display on the adequacy or correctness of student input. Meta-responses are all displays produced by the agent. These can be synchronous, generated by responses to a student meta-request, or asynchronously, generated by events sent to the agent from the materials. Questions are a particular form of response or meta-response which seek further student input. Questions engage the student in a form of a dialogue which is an integral component of the tutoring interaction.

Fig. 5 illustrates an exemplary segment of the interaction of the student and the system that can occur during a mathematics homework. It illustrates both how responses and requests are distinguished from meta-responses, and meta-requests and also how the agent, through its observation of the student's current situation and its

contact with past student history, is able to guide the student better than the materials alone, which are only aware of the current context. This display is individualized to the student's current and past performance and preferably
5 uses realistic, life-like on-screen personae to engage the student. Displays from the ABI System directed to the student are indicated generally on the right; inputs from the student directed to the ABI system are indicated generally on the left; and time increases downward. The diagonal arrows,
10 as at 401, indicate that the message at the arrow's tail leads to the message at the arrow's head.

This illustration begins with response 402 from the mathematics homework materials suggesting that the student use the calculator tool. The student responds with request
15 403 which selects the calculator icon to request the calculator. Calculator application 404 is then activated and displayed by system components. Data 405 is a student input to which the calculator tool, and response 406 indicates a student error. This response was apparently not sufficiently
20 informative, and data 407 is a repeated incorrect input to the calculator tool. The student's agent observes the course of this interaction as the calculator tool sends event messages to the agent. Upon observing the repeated wrong input, the agent intervenes with a asynchronous meta-response
25 408 summarizing recent student inputs. The student responds with meta-request 409 to the on-screen agent for help, since the tool responses were apparently not sufficiently helpful. The agent's synchronous meta-response 410 suggests for consideration an entirely different approach to correct the
30 student's recent error.

5.3.1.3. System Responses

The following general principles preferably guide system and materials responses and agent meta-responses. First,
35 some display is to be made on every user input, if only to echo a character or mouse click. Second, a user is never to be left in doubt about the status of current tasks. For

example, the system preferably provides task specific hints or suggestions if no user input is received in a time period adaptively determined. Third, all responses reflect the current context.

5 Further, importantly, aspects of system responses should be adapted to the particular student audience, from elementary to adult education and including special classes of students. This tailoring can be set by the teaching or administrative staff. One adaptable aspect is the language
10 level and the language of system responses - for example, the vocabulary and language of help services, messages, and tutorials - is preferably adjustable. Another important adaptable aspect is the type of personae of the on-screen agent is preferably adjustable. The types of encouragement,
15 level of jokes, and so forth, depend closely on the intended student population and are advantageously adjustable. Further, tools are also adaptable. Each tool is also advantageously enabled or disabled for each student. Mail and communications tools, for example, can be made
20 unavailable for the lower grades. File creation and deletion can require strict controls. Also, certain tools can have differing complexity levels suitable for differing student levels.

In addition, certain ABI system components have
25 particular preferable and advantageous features. These are listed subsequently. Importantly, meta-response selection is preferably shaped in view of the student's past baselines of speed, performance accuracy, modality, as specific to the type of materials. Moving average functions, in which recent
30 values are given higher weight than earlier values, can be used advantageously to generate baselines of performance and timing. The timing of meta-responses is preferably based on student data object fields that record the amount of help asked for in the past and past performance provided.

35 Further, the pacing of meta-responses is advantageously context sensitive. For example, remediation should be offered only in case of repeated error or hints offered

asynchronously only after a relatively long period without an answer. Also, previous student interactions should be utilized. Repeated requests for hints should be noted and dealt with perhaps not with another hint but with
5 remediation. The rate of prompts, advice, and hints should be adaptively adjusted on the basis of ongoing performance records.

The actual content of a meta-response can be adjusted to the current situation by filling in parameters from event
10 messages sent from the materials. See *infra*. The Instructional Materials Interface Standard ("IMIS") is a key element in providing information to the student in response to inquiries such as "Where am I?". The system then uses the information in the IMIS to respond, "You are halfway through
15 the drill and practice on fractions," for example. A student request for further information can elicit a graphical response. The graphical responses reinforce the virtual tutoring aspect of the system by providing a greater level of detail in a format similar to that presented by a human
20 tutor. The format of the graphical method used is individualized to the student's past use of system components such as previous graphical meta-responses and tools such as the scheduler/calendar.

The structural information for the agent software to
25 construct graphical responses is derived from lesson notations, previous student performance, previous agent responses (including graphical responses) and the scheduler/calendar. Marker requests use general notations for the type of lessons and specific notations for
30 prerequisites. Temporal requests use notations of expected time together with profile information on individual performance on that type of material.

Typical predefined graphical response templates include road maps (perhaps in the form of a train and subway map),
35 charts, table, graphics and icon flow charts. Colors can be used to show relative levels of performance, urgency or dependency of elements. In response to a 'How am I doing'

request, green might indicate good performance; yellow, adequate performance; and red, needs immediate attention. Similarly, the shape of the icon might indicate its function such as a diamond for caution or a hexagon for stop.

5 Figure 12 illustrates an exemplary dialogue starting with the student meta-request 'where am I?'. The on-screen agent then make a meta-response containing a summary of the student's progress, for example "You are one quarter through the lesson on adding fractions." Next, the student might
10 request further information. Preferably the on-screen agent will point to the location on the diagram and say "You are here." If the student then clicks on an element of the chart, the agent will provide further information. For example, clicking on the Practice Box will provide a meta-
15 response containing a flow chart of this upcoming activity, as generally illustrated.

Preferable Calendar/Scheduler Responses And Their Selection

The calendar scheduler is advantageously capable of
20 providing the following responses. These are controlled by schedule data fetched from school-student data areas and are processed by the calendar/schedule tool. Preferably, the student data object contains only personal schedule data for the student. The calendar/schedule tool and the student's
25 agent can obtain schedule data both from school-student areas and from the student's personal schedule areas.

1. Schedule reminder responses, which remind the student of deadlines for materials tasks in the system or for external activities, such as getting a parent's approval for
30 a class outing.

2. Task sequencing suggestion responses, which suggest an order of assigned tasks based on student history and on the assigned priority and deadline.

3. Timing estimate responses, which estimate how long a
35 task will take based on timing information entered as part of task in the instructional materials and on past relative performance for this student.

In one embodiment, the ABI system provides for of scheduling initiative to be divided between the student and the system. Settable task schedule parameters permit, at one extreme, the student to have complete scheduling control, 5 able to initiate and to exit any activity at will, and limit, at the other extreme, the student to work on only those materials that the system schedules. These schedule parameters include those controlling the tools and options available to the student while performing a given task and 10 those requiring the student to perform background reading or remediation. Important initiative parameters include the scheduling values of task priority value and deadline. If the priority and date are not both "off", those tasks with greater priority and earlier deadline are automatically 15 scheduled for the student. If these values are "off", the student has control of task scheduling.

The system of this invention also includes a central list of timed activities, perhaps stored on the server systems, to be performed by the system. These can include 20 regular times for the generation and printing of standard reports or for the broadcasting messages concerning group activities such as spelling bees. These timed activities can be performed by scheduling software which compiles the timed activity lists and initiates the listed activities at their 25 listed times. Such scheduling software can be similar to the "at" utility in UNIX operating systems.

5.3.2. Teacher/Administrator-System Interface

In the case where a teacher supervises a student's 30 education, the teacher or the teacher's representative plays an important role in the ABI system. The teacher uses the system to perform such functions as entering initial profiles in student data objects and school-student data areas, assigning students to subgroups, previewing, annotating and 35 scheduling assignments, reviewing and commenting on completed homework assignments, and reviewing summary reports.

In this setting, the agent of the student is also an agent of the student's teacher in that the student's teacher controls key parameters in the student data object and the school-student data area, which in turn can direct agent actions. The teacher customizes the ABI system by initializing and supervising school-student area and student data object parameters, assigning and prioritizing assignments, and customizing materials. Important teacher activities are included in the following list.

1. The teacher initializes and exercises continuing control over important data in the school-student data, and in this manner supervises the student's use of the system. For example, the teacher controls the access and level of tools available to the student and limits the extent to which the student can alter agent personae.
2. The teacher controls the student's use of the ABI system by assigning, scheduling, and prioritizing the student's access to the materials. This is accomplished by teacher control over the schedule subtype in the school-student data areas. For example, the teacher can schedule tasks that must be completed on the ABI system, schedule non-system tasks, remove tasks or modify their priorities.
3. The teacher can customize materials available to the students. The extent of routine customization includes modifying sequencing of instructional lessons, elements, and items, choosing the homeworks the student must complete, specifying the formats of homework assignments having some student discretion, such as reports, sending messages to students.
4. The teacher's class management is aided by a facility to send messages, reminders, hints, etc. to students using the ABI system e-mail facilities.

The system can advantageously assist the teacher in homework management. Once the student completes and submits a homework assignment, a printed copy can be made for the teacher and the student. The homework assignment can be graded by the ABI system, if answers were provided as part of

homework material. The teacher can add comments for the student, if homework is viewed online by teacher.

The system can advantageously also provide the teacher with summary and detail reports for each student and class. 5 These reports can be immediately available online or printed for later review. As known in the art, reports can contain both current and cumulative data on instructional progress and homework assignments. The reports can also flag patterns of deficiency in a student's homework and problems in a 10 student's instructional progress. In a preferred embodiment, these reports are generated from the database of school-student data forwarded to the school server systems by the students' agents.

Additionally, the teacher can be a student. A teacher 15 can benefit from training in the use of the ABI system in general, in the procedures to customize materials, and in the characteristics of the particular materials used in that teacher's class. This training can advantageously be packaged as instructional materials directed to the teacher 20 which are otherwise similar to student instructional materials. In this case, the teacher, like the student, has accessible materials, a teacher data object recording the teacher's progress and pedagogical characteristics, and an agent using this data object to guide the teacher's training 25 and guide the teacher in the use of the system. As for the students, the teacher data objects can advantageously be stored as portable teacher data objects.

Other actors, such as school administrative staff, parents, and researchers, can play a role in the ABI system. 30 Administrative staff can have privileged access to certain data items in the student and teacher data objects and other system data, which permits them to assign students to courses, to assign students to teachers, and to establish instructional performance standards and criteria which the 35 students must meet to complete their materials. This staff can also receive online or paper reports on the progress of

students in the schools, the effectiveness of teachers, and the usefulness of the particular materials assigned.

Reports and queries

5 Generation of reports from databases, either relational or object-oriented, is a standard programming task. The key elements of this task are the selection of data to appear in the report, the way in which selected data is to be presented whether in a summary form, a detail form, or both, the format
10 in which the data is output, and the layout of data output elements on the screen or page.

The teacher and administrators require several types of reports. Periodic reports need to be generated at regular intervals. These vary according to population: by student,
15 by class, by grade, by school. They also vary by subject. The reports can present/summarize complete sets of data or only data exceeding stated limits. Some of these reports fulfill mandatory reporting and record keeping requirements, and some are sent to parents. The ABI system also provides
20 teachers and administrators with standard querying and report generating capabilities.

If appropriate, parents can also be actors in an embodiment of the ABI system. A student's parents can be given access to certain fields in their student's data object
25 and school-student data areas in order that they can receive rapid information on their child's assignments and performance. This information can be made available at home on the same client system that their student receives instruction and homework.

30 Finally, educational researchers can receive certain access to ABI systems in order to research the effectiveness of educational theories and methods. For example, they can efficiently compare the effectiveness of various educational paradigms in certain instructional contexts by receiving
35 reports relating to students pursuing materials constructed according to the paradigms of interest.

5.3.3. Instructional Designer-System Interface Designer Interface Overview

Materials, in particular instructional materials, are authored by instructional designers. Authoring of materials can be done on the system on which the materials are to be used, or alternatively, on a separate system. Generally, an instructional designer authors materials including, for example, computer assisted instruction as known in the art, computer assisted exercises such a homework or simulation, and computer managed student instructional tasks which can involve work with several materials. For all materials, the student's agent must be informed of the sections completed and skills acquired in standard formats.

15 Designer Interface Details

The ABI system provides an environment in which the student's agent is available to control materials presentation and guide the student to improve educational outcomes. This environment includes facilities to present assignments, assess responses, probe for prerequisites, offer assistance with tools such as dictionaries, and score unit mastery quizzes. The system can advantageously include conventional forms of homework, such as work sheets, as well as new types of homework, such as group-based homework, and formats previously too time consuming for teachers, such as criterion based rather than fixed length or interactive rather than prescriptive. Advantageously, the system structure can accommodate existing forms of computer assisted instruction by embedding such existing instruction in materials of this invention which contain notations and generate agent event messages.

All authoring information below can be provided by the instructional designer, if preferred. In this case, defaults allow the teacher to enter only overriding information where needed. Alternatively, the teacher can be allowed or required to make various degrees of customization. In this

section, the term "exercise" means a single unit of an instructional task.

The run-time conversion of materials with descriptions of text, graphics and animation advantageously is performed by methods commonly used in interactive multimedia Authoring Software. Existing authoring programs let the author specify the attributes and behavior of multiple independent display objects through such programming paradigms as visual programming or scripting languages. For example, to display a button or other selectable object, a user of authoring software specifies such characteristics as position, attributes such as size, shape, color, and label, and the function invoked by the object selection.

Among the most widely used of the many available products are Macromedia's Authorware and Director, Asymetrix's Multimedia Toolbook and Aimtech's IconAuthor. These programs have been documented by their manufacturers and other writers (Sims, *Authorware with Style*; Swearington et al., *Macromedia Director Design Guide*; Hill, *Using Multimedia Toolbook 3.0*).

The process of authoring an instructional task is advantageously described sequentially to include the steps of, for example, defining the task, defining each exercise, judging student inputs, defining exercise completion, and augmenting the materials with notations for the agent.

In the authoring step of defining the task, the instructional designer advantageously provides information including initial instructions for the entire task in a written and preferably also a spoken format with alternative wordings as necessary for special classes of students. The designer also provides materials sequencing in accord with the education paradigm chosen. Instructional sequencing is appropriate for interactive instruction with feedback. Homework sequencing can include a fixed order; a student defined order; a student defined order assisted by teacher prioritization into such priority groups as essential,

important, or optional; and sequencing defined by performance to criterion on individual item subtypes.

In the authoring step of defining each exercise, the instructional designer advantageously provides information including the following. The designer chooses names for this task and exercise, its prerequisites, and the skills to be acquired in accordance with school system standards so that the agent can meaningfully track student performance and provide helps, hints, and remediation. Next, the designer provides student instructions for the exercise, preferably in both spoken and written formats. Next, the designer specifies the presentation of the exercise by creating graphics and text for the exercise and by specifying their display attributes. Next, the designer defines allowable user inputs, the data type of input, and the display areas in which input is allowed. Finally, the instructional designer provides hints. Hints preferably include optional hints offered on student request or student inactivity and hints offered by the agent in case of totally inappropriate actions.

In the authoring step of judging student inputs, the instructional designer advantageously provides information including the following. First, the designer defines standards for the completeness of requested inputs and actions, possibly none, in case of incomplete inputs. An exemplary such action is suggesting the completion of omitted inputs. Second, the designer selects how inputs are to be judged and the possible judgements, for example, correct, near miss, incorrect, and so forth. Finally, the designer selects error responses to individual input elements or an entire exercise. These responses can be uniform or can reflect the specific wrong answer. Error responses include retry policies and selection of remediation paths. Remediation can be item sequencing options given on the basis of retry outcome.

It is preferable that response judging be performed according to certain standards established for a particular

implementation of this invention. Thereby, the agent can monitor the student's pedagogic characteristics in a uniform fashion across all standardized materials. Accordingly, a first step in input judging can be, where appropriate, 5 checking the data type and perhaps range of an input. For example, checking that a fraction is entered in response to a fraction addition problem. Appropriate feedback can be given if the wrong data type or range is input. Single student inputs can include entry of a single text or numeric element, 10 movement of a single display object, selection of a single display object, or drawing a line or curve perhaps encircling a display object.

A second step in input judging can be classification of a suitable input in standard error categories. In an 15 exemplary embodiment, this can be performed by providing a pattern corresponding to a correct answer. The patterns can be a template appropriate to the suitable input, such as a text template or a spatial template. A pattern matching procedure selected from a system library of such procedures 20 can be executed to match the input to the pattern. The output of the system matching procedure is advantageously selected from a limited number of standard judgements of correctness and partial correctness. This judgement is then communicated to the agent in an event message in order for it 25 to guide its student and adapt its pedagogic model. This invention is adaptable to templates and pattern matching procedures known in the art. Patterns can include one or more parametrized text templates, spatial templates defining the relative positions of objects to be moved by the student, 30 selection templates specifying patterns of selections. Further, spatial templates can include outlining areas of the screen, shapes of drawn objects, maze traversal, and tool inputs.

Turning to the authoring step of defining task 35 completion, the instructional designer advantageously provides information including standards for input, exercise, and task completion. The materials can require a certain

minimum completion before allowing homework submission to the teacher.

The final authoring step is augmenting the materials with additional notations for the agent. These notations concern task and exercise subject, skill classifications, and definition of the educational paradigm embodied in the sequencing logic. It is performed by instructional designers or knowledgeable teachers, and is expressed as notations in the materials that generate event messages for the agent and that reference control parameters set by the agent for control of materials sequencing. The notations so entered communicate various types of information to the agent. Exemplary types include characterization of assignment by type of task, subject, elements of subject covered by task; comparison between exercises in same assignment by similarity and difficulty; the subject matter prerequisites to determine what the student may or may not have mastered based on which exercises are answered correctly; system knowledge prerequisites; and scheduling information such as average and expected time to complete.

5.4. ABI System Software Structure

This section describes in a more detailed fashion an exemplary structure for the software components previously described in a more general fashion with reference to Fig. 2. Subsequent sections describe particular components in an even more detailed fashion. The structure described here is exemplary. This invention is adaptable to other structures with other allocation of the functions of this invention to different modules. Such alternative structures are easily designed by those of skill in the arts.

This section first describes the principal client software and data components and the conceptual hierarchy which reflects their interaction. Next, the structure of the executive software is described. Finally, the flow and processing of events through the system are described.

5.4.1. Student Client Software Structure

Fig. 6 illustrates the principal client software and data components and the conceptual hierarchy which reflects their interaction. The links illustrated represent principal
5 procedure call or class dependencies among the components. At the root of the hierarchy is operating system 601, which has been previously discussed in connection with the preferred client hardware. The operating system ("OS") includes the operating system proper together with
10 implementation languages and their class and function libraries with associated controls. At the next level is executive software 602 ("ES"). This software collects a number of components which customize the operating system to the requirements of this invention and also extend it, if
15 needed. For example, all OS task creation is processed through an ES task control facility to insure that the student accesses only permitted materials. The ES software also provides a preferred animation facility and controls client startup.

20 Session and screen manager 603 is always present on a client system. This component partitions the screen into the areas for the principal system components, as has been generally illustrated by the exemplary screen of Fig. 3, and controls the system area, area 302 in Fig. 3. Thus, upon
25 student selection of an icon presented in the system area requesting the ES to start the function represented, it turn checks with schedule/calendar 607 whether the student is currently permitted to access this function before continuing with OS task creation. The system manager also presents
30 whatever reward graphics and animation the student has been granted access to. These functions are performed by calling the object level I/O facilities of the OS and ES.

Also accessible on a client system is student data object 611 for the student in session on the client. This
35 object, preferably including ABI system data relating to the agent's model of the student, to the student's current instructional state, and to the instructional materials

themselves, is preferably accessed as previously described from portable media. Alternatively, it can be downloaded from the server systems when the student logs onto the client. Preferably, this object is divided into components 5 including methods and data subtypes, and those only those components required are actually accessed at any one time. As indicated by double headed arrow 616, the student data object is accessed and updated primarily by agent processing functions 609 and 612.

10 In a preferred embodiment, school specific data is separately stored in school-student data areas 615. As indicated by arrows 608 and 614, this data is preferably accessed by ABI client system components other than the agent. School-student data is preferably accessed from 15 databases on school servers. In alternative embodiments, various subtypes, or all, of school-student data can be combined into student data object 611.

Schedule/calendar component 607 is important for management of the student by other system actors, such as 20 teachers and administrators. It is a tool that is always active whether or not it has a screen presence. Activities for the student, represented by activity description, priority, and deadline, are entered into the schedule/calendar data subtype of the school-student data 25 areas by teachers or administrators. Optionally prerequisite information can also be entered into the schedule/calendar subtype. As indicated by arrow 608, this component references this schedule/calendar subtype data as well as the time expected for the student to complete an activity, as 30 determined from the student's past performance and stored in the student data object, in order to determine whether certain activities, such as particular instructional materials, should be automatically started by the ES without any student intervention. In cases where the student is 35 permitted greater initiative, the schedule/calendar can permit OS task creation requested by the student, as by selecting an icon. This component also provides, on request,

prioritized lists of tasks for the agent to present to its student when the student asks for advice on what to do next. It uses priority and deadline information and time-for-completion data computed using data in the instructional materials and student data object.

The materials are represented in the ABI System by materials engine 604 and materials data 605. As previously described, the materials data comprises objects for display output or student input, sequencing logic controlling object display, and notations which when referenced by the sequencing logic during object presentation generate event messages for the agent. Materials data is advantageously grouped into "entries" comprising those objects, logic sections, and notations related to the display of a single screen or a few screens related to a single educational item. The materials data also preferably include a special header or initialization entry with important notations that communicate to the agent the educational paradigm adopted by these materials and can inform the agent of the control variables to which it is responsive. Such header or initialization messages are also preferably sent to the agent if the materials change their education paradigm. In a preferred embodiment, there is one common materials engine 604 which presents a plurality of materials data 605. In alternative embodiment, there can be specialized materials engines for various classes or types of materials data.

Materials engine 604 downloads the entries of materials data 605, interprets the sequencing logic, displays objects as requested, and references embedded notations generating the requested event messages to the agent. Standard facilities of the OS and ES are used for object presentation and for routing any input to the materials. Input is processed according to specifications in the sequencing logic. In a preferred embodiment, the agent controls the materials by setting shared global variables which the sequencing logic checks. Such shared global variables can be made available by OS inter-process communication ("ipc")

facilities, such as shared memory. The materials engine can be any program implementing these requirements, in particular an extension of available commercial authoring tools and engines, such as Macromedia's Authorware.

5 In an alternative embodiment, the materials are not separated into an engine and a data component but consist of one unitary component for each material. In this embodiment, a process similar to compiling creates a single executable materials component. This invention is equally adaptable to
10 other implementations of the materials that generate agent messages and are responsive to agent control according to the requirements outlined herein.

Agent processing is divided into two components, agent action processing 609, which determines agent display actions
15 in response to events, and agent behavior processing 612, which transforms display actions into displays of personae to the student. As indicated by arrow 616, both components access student object 611. In a preferred embodiment, agent action processing is rule based and event driven. Rules in
20 rules tables 610 are evaluated using parameters both communicated in event messages from the materials or the student and retrieved from the student data object. These rules propose candidate actions and then weigh and select a final set of agent actions from the candidates, which are
25 communicated to subsequent agent behavior processing 612. Agent processing also sets global variables for materials sequencing and control. A side effect of this processing is the updating the student data object with information from the materials event message.

30 Agent behavior processing 612 constructs an on-screen agent display based on the actions determined in agent action processing. In a preferred embodiment, this processing is based on behavior tables 613. Utterances, text or voice, and affects are selected from tables based on the determined
35 final actions and refined with parameters included with the actions. The utterances and actions are sent to the selected agent persona object, which creates the agent display of the

selected personae using the utterances and effect selected. Data is referenced and updated in the student data object by this processing, in particular fields reflecting the student's agent personalization choices, such as the desired personae, and fields reflecting recent agent behaviors.

Also illustrated is communication materials 615. These materials manage and provide resources for various group activities, such as student tutoring, group work with particular materials, and group contests. As indicated by arrow 614, these materials access data subtypes preferably stored in school-student data 615.

5.4.2. The Executive Software

The executive software ("ES") collects together a number of components which customize the operating system to the requirements of this invention and, if needed, also extend it. ES software implements common and special facilities. Exemplary common facilities include task control, communications, and I/O facilities; exemplary special facilities include a preferred animation facility and a client logon and startup facility. In a preferred implementation, ES software is built as frontends, wrappers, or extensions to available OS software components. For example, certain facilities can be implemented in C or C++ and directly call OS interfaces, such as the Windows™ graphics device interface or its extensions. Other facilities can be built as classes using available implementation language libraries, such as the packages in Java™ 1.0. Yet other facilities can be provided directly as part of software packages, such as the display I/O functions present in commercially available authoring packages.

The task control facility manages the startup of system components. First, it verifies that the student is permitted to activate a requested component by checking schedules and priorities with the schedule/calendar tool. Indirectly, the student's agent can be queried to determine if this activation is reasonable. Next, if permitted, this facility

manages the loading of required software from server systems and the accessing of data objects. Finally, task control then starts up the component by making any necessary OS calls. Task control also notifies other system components at 5 task terminations.

The communications facility manages network communications and provides whatever client-server or file server protocols are not present in the OS. Such protocols might include HTTP V2.0 with URL name resolution. It 10 maintains all necessary network sessions, including sessions with the major classes of servers, including executable software servers and instructional material servers. In the case of portable student data objects, communication is also maintained with the registry function. In case of downloaded 15 student data objects, communication is maintained with student data objects repositories. Data snip libraries can reside on any of these server classes. In alternative implementations these servers can be on one or several physical server systems. Finally, this facility handles all 20 remote access requests for information including requests for downloading and uploading.

The I/O facilities includes input and output display handlers for object level display I/O. The display handlers receive object level requests for text, graphics, video and 25 audio and translate them into whatever interface is supported by the OS. The input handler receives low-level inputs from the OS input handlers and processes them according to the current screen format. In certain cases, it can directly call the output handler to perform immediate feedback 30 actions, such as highlighting or dragging an object. In other cases, it can pass I/O event messages in an appropriate format to the system component owning that screen object, for example, the on-screen agent. The output handler receives object presentation specifications, such as system owner, 35 position, characteristics, size, any animation information, and whether the object is an input focus, then updates any necessary screen mapping, and generates OS requests to

display the object. An example of such an object specification includes a selectable text field object with specified contents, perhaps scrollable, displayed by a particular instructional material.

5 Exemplary specialized ES facilities are animation and client startup. It is preferable that the client system support animation, which is a connected and timed sequence of displays potentially calling on all display modalities available, and other timed presentations. Although this
10 invention is adaptable to any suitable animation facility, a preferred facility presents a script based interface.

The inputs to an animation facility are scripts which comprise object display commands, the timing of the object displays, an input specification of how any permitted user
15 inputs are to be handled, and the types of events to be returned to the initiating system component. Examples of display events include user input causing script branching and termination or interruption. The animation facility receives a script from another system component, requests
20 downloading of necessary display objects, for example from data snip libraries, interprets the timing specification, and sends request to the input and output handlers.

The ES startup facility is described herein with respect to a student client to run on a network attached computer.
25 Startup is similar for other client systems, including teacher and instructional designer clients. Each component of the ABI system must be downloaded from a server when needed or accessed from portable media, if as is typical, no component of the system is resident on a client prior to
30 startup. The initial step involves the student accessing any client attached to an ABI network. Accessing can involve as little as powering-on the computer and requesting startup of the system on this client. Preferably, accessing by a student user begins by accessing the server with the system
35 manager, for example, using a standard intranet browser which can be resident on the client or downloaded by a power-on bootstrap process. The student logs on to the system

manager, which then performs authentication, for example, by means such as password or identification card. Upon successful authentication, the system manager downloads and starts the ES. The ES then initiates necessary communication sessions, including those with the system servers, and then downloads the session manager software, the agent software, and the scheduler/calendar tool software. Preferably, the portable student data object in conjunction with the ES then authenticates the student and the student data object data is accessed from the portable media. Alternatively, the student data object is downloaded from a server. Then the session manager presents the student display in a form depending on student preferences in the student data object and receives input from the system area of the display. The schedule/calendar in cooperation with the agent then determines what materials the student is to be presented with or can select from. Finally, the materials data and engine are then downloaded and the substance of the student session commences.

Presentations of personae or merely appropriate coherent responses can be created from audio and video display-objects downloaded from a server and referenced upon demand. These display objects, or data snips, can be linked into groups corresponding to the particular presentations. Further, these linked groups can include small pieces of code that allow for a branching and interactive short meta-response. Thus, one meta-response can include opportunities for student input with the next display object being chosen in response to that input. Each of these groups is catalogued and referenced as that persona behaving in a particular manner.

5.4.3. System Event Processing

The ABI System on the student client, and on other clients, is advantageously organized to wait for student and timer input events and then to respond appropriately to these events. This is common current practice for constructing interactive systems. However, this invention is adaptable to

practices that might be developed in the future for constructing interactive systems as long as the principal system components and their mutual interactions as previously described can be represented in such a future practice.

5 With reference to Fig. 7, this section sequentially describes the system processing of an input event and its consequences from initial input until the system waits for the next event. This description provides detail of how the system components communicate with each other and of how
10 information and control flows through the system. More detailed description of the individual components appears in following sections.

Fig. 7 conceptually illustrates control flow and event processing in a student client. Generally, at the left of
15 this figure is relevant data; in the center is processing steps; and at the right are I/O events. As is apparent from the context, the arrows in this diagram represent either data references or control flow. The control flow is at times implemented by information bearing messages and at other
20 times effected by standard ES and OS system calls. Further, this figure is directed to the processing of those components that interact with the student's agent. Those components, such as the session manager, which do not interact with the agent can be constructed according to standard interactive
25 techniques (see, e.g., Petzold, 1996, Programming Windows® 95, Microsoft Press, Redmond WA).

Thus, at wait point 701 the system waits for the next student input or timer event. This wait commences at wait points 707, 713 and 717 after the system completes processing
30 of the previous event, or possibly after system startup. Upon receiving an input event, ES I/O handlers 702 decide whether the event represents an action without significance for other system components. For example, the event can be a student action causing only the highlighting of an object or
35 a timer event directing an animation. Such events can be entirely processed by the I/O handlers, and system waiting resumes at 701. If the event represents a student request

for the materials engine 703 or a meta-request for the agent 711, the I/O handlers format it appropriately and communicates it to the correct component owning that input object. If the event represents a time interval set by one of the materials engines or by the agent, it is formatted and passed to the requesting component. In the case of group work, the event can be generated on a remote computer system and transmitted over a network link in order to reach the local I/O handlers.

10 The I/O handlers format event messages into the format expected by the component they are directed to. They include in each message an indication of the type of student action or time interval along with any input information from the action. One input event can generate several events
15 messages.

 Herein, messages directed to materials engines 703 are considered first; messages directed to agent action processing 711 are considered second. Although Fig. 7 illustrates two materials engines, one engine or more than
20 two engines are possible on a system from time to time. Regardless of the number of materials engines present, event messages are communicated to the correct engine. The materials engines 703 process a plurality of read-only materials data 704 representing instructional materials,
25 tools, and communication materials. As indicated by arrow 725, these engines also access control information determined by agent action processing 711. This control information can be accessed in any convenient manner, such as by an exchange of messages or by referencing parameters stored in a shared
30 memory region. This information controls the materials engines at educationally significant points during their materials presentation. Optionally, materials engines 703 can also access remote databases 705 and other remote resources available through the system network. The engines
35 use these two sources, and optionally three sources, of input to cause presentation 706 to the student of, for example, an instructional lesson, a homework exercise, an instructional

tool, or a joint educational contest. This presentation uses the I/O handler of the ES and OS to generate actual student display.

As indicated by arrow 727, the materials engines also
5 generate messages directed to agent action processing 711. At educationally significant points during materials presentation, notations in the materials cause the engines to format a message to the agent. These messages also include an indication of event type and relevant data, perhaps
10 including timing data. One student input can generate several agent messages. At points which are not educationally significant, the materials can not generate agent messages. Thus, the system can wait again for the next student action at wait point 707 if the previous student
15 action had either no input significance for the materials or agent or no educational significance for the agent.

However, if messages have been sent to the agent, agent action processing 711 is activated. In the preferred but not limiting embodiment, this processing is table based. Rules
20 from policy filter table 708 are evaluated in view of the data included in an incoming event message and in view of data on the student's past performance and the student's pedagogic model in student data object 712. For example, comparisons with student history are needed to determine
25 relative performance. These rules propose candidate agent actions. Next, rules in decision weight table 709 and in selection criteria table 710 filter the proposed actions into a final list of agent actions. These final actions can cause the update of the information in student data object 712 with
30 data on the student's current performance and behavior, as indicated by double headed arrow 728. They can also make available control information for the materials, as indicated by arrow 725. Finally, and importantly, the actions can include display actions for causing visible agent behavior.
35 The list of final display actions is sent to agent behavior processing 716. It is possible that no visible agent behavior is appropriate and that the list of display actions

is empty. In this case the system waits for further student input actions at wait point 713.

Agent behavior processing 716 processes the final list of display actions communicated from agent action processing 5 711 in view of utterance tables 714, display behavior tables 715, preferences and the record of recent agent behavior in student data object 712 in order to generate a coherent display of the on-screen agent personae reacting to the previous actions. The final actions select utterance 10 templates which are completed with parameters contained in the actions. The personae from the display behavior table selected according to the student preferences use these complete utterances to generate display objects, and perhaps animation scripts or applets, which are sent to the I/O 15 facilities of the ES for final display 718. Agent behavior processing also updates the student data object with information concerning this current behavior.

Having completed all possible processing of the student input action, the system now waits at wait point 717 for the 20 next student action or time interval.

5.5. The Instructional Materials And The Tools

This section describes a preferred embodiment for the instructional materials, the student tools, and 25 communications materials. In this embodiment, the materials have a uniform structure, being defined by materials data which is used by the materials engine to appropriately generate displays and perform functions. This uniform structure permits a uniform handling of the interface between 30 all the materials and the agent. In alternative embodiments, certain tools and the group communication materials, for example, can be advantageously separately implemented as separate programs that themselves maintain the necessary agent interface. Such certain tools include a calculator, a 35 dictionary, an encyclopedia, and group communications. In further alternative embodiments, each instructional material

could be a separate program that also maintained the necessary agent interface.

This section first describes the general structure of the instructional materials and then describes the tools typically available on an ABI system.

5.5.1. The Instructional Materials

In a preferred embodiment a common materials engine interprets specific materials data to perform instructional and tools functions. These are described with reference to instructional materials with adaptations needed for the other materials noted. Turning first to the materials data, in the preferred embodiment it includes three principal sections for presentation items, sequencing logic, and notations. The presentation items include whatever is displayed, preferably represented as display objects, which can be parametrized. These display objects can be packaged with the materials data or can be downloaded from a server on demand. The notations contain additional data related to the materials display. These include, for example, prerequisites, links to related material, expected student performance, and help and hints. The notations are preferably generated from templates referencing parameters from the materials data and student performance inputs. The materials engine uses notations to generate messages to the agent, which comprise one part of the agent interface. The sequencing logic is executable or interpreted code that animates the particular materials. It references all data in the particular materials to cause the ordered display of the presentation items and to send messages to the agent according to the notations.

The materials data is advantageously grouped into entries, each entry representing a minimum item of presentation, which can, however, involve several screens. These entries are preferably specialized at least into a header or initialization entry and the other entries. Table 2A illustrates a typical materials header entry which is the first entry processed when the materials are initialized.

TABLE 2A: HEADER ENTRY

	Instructional Header Entry		
5	Presentation items	Sequencing Logic	Notations
10		Global variables; Global functions; Local variables; Local functions;	Prerequisites for materials; Reference to other materials or standard texts. Agent initializing information including: - meaning of global variables; - education paradigm adopted - available helps, tools

15

This header has several particular features. The sequencing logic for the header frame consists largely of definitions of variables and functions. The global variables are shared between system components and include the control variables that the agent sets and that the sequencing logic references and tests in order to be guided by agent control. These variables, which comprise another part of the agent interface, for example, can control the time pacing of instruction, the new concept seeding rate, the density of new examples, the time pacing, or the difficulty of discriminations. Local variables are available to the sequencing logic during materials processing. Global functions are those global system functions that can be called by the sequencing logic. Also, dictionary lookup, spell checking, or encyclopedia lookup can be globally implemented and shared. In a Windows™ environment, the global functions can be DLLs. Finally, local functions are available locally to the sequencing logic. For example, in a scientific calculator tool, computations can be local functions. For a further example, in instructional materials the local functions are available for checking user inputs for correctness, scoring quizzes, and so forth.

The notations in the header entry generate materials initialization messages to the agent. These messages inform the agent about these materials, about what global variables they respond to, about what helps, hints, and tools are useful, and importantly about the educational paradigm the materials use. Preferably, information about this paradigm is structured according to the instructional materials interface standard. See *infra*. The notations can also contain additional information, such as prerequisites for the whole materials and references to other materials and texts. Finally, the presentation item can be, for example, an introductory screen.

Table 2B illustrates a typical entry which is processed during regular materials presentation.

TABLE 2B: MATERIALS ENTRY

	Instructional Entry N		
20	Presentation items	Sequencing Logic	Notations
25	Display objects, possibly including those for text, graphics, sound, animation, or video	Interpreted or executed control statements referencing variables, notations, and any student input, and causing display of display objects and execution of notations	Prerequisites for frame; Expected timing, and difficulty; Relation to other frames; Links to other materials and sources. Changes to agent initializing information; Student performance data; Student error data
30			

For this entry, the presentation items are those for the materials display. The sequencing logic causes this display in view of the variables and other information in the materials data and any student input. Finally, the notations result in agent messages reporting changes in any parameters set at initialization, student performance data, student

errors, and other educationally significant information. The notations can also contain information specific to this frame, such as expected difficulty and timing.

Turning now to the materials engine, its first processing step is to request the executive software to download the requested materials data from the instructional materials server. It next processes the header entry, links to global variables and functions, and sends initialization event messages to the agent. When presentation begins, it interprets or calls for execution the sequencing logic on the first frame. From this frame it proceeds to activate other frames as directed by the sequencing logic. Lastly, when the materials processing ends, any termination messages as directed by the notations are sent to the agent and the materials are deleted from the client.

In a preferred embodiment, the materials are all implemented similarly. Most differences between the instructional materials, tools, and communication materials are in the presentation items and the sequencing logic, including different global and local entities. All materials are expected to have notations for generating agent messages that record materials initiation and termination and student performance and errors. Preferably this information is reported in a standardized manner according to an instructional materials interface standard. See *infra*.

5.5.2. The Tools

The ABI system is adaptable to a wide range of necessary and optional student and teacher tools tailored to the students and the courses of instructions. In the case of elementary education, the following preferable tools include certain general tools and the communication, or joint work, materials. In the case of commercial education, other tools can be preferable. The schedule/calendar tool participates in permitting access to materials according to student schedule and is preferably found in all embodiments.

The discussion in the section is directed to an implementation for elementary education. It is not limiting in the tools that can be used in an implementation.

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5.5.2.1. The General Tools

The general tools are preferably present in a range of forms selected according to data in the school-student data areas, including grade level, and teacher permissions. One general tool is a calculator, which can have forms varying
10 from a simple four function calculator to a complex graphing calculator. Other general tools include language tools, such as a spelling checker, a thesaurus, a word pronouncer, an encyclopedia, and a dictionary. Different levels of each language tool can be provided suitable for different grade
15 levels. In an alternative embodiment, the language tools can be integrated with a "starfish" tool, which allows the user to place the center of a "starfish" over a particular word, and then, by selecting the appropriate arm of the starfish to obtain the definition, a pronunciation of the word, a rhyming
20 word, a synonym, or an antonym. Another general tool is a word processor, perhaps with a drawing mode which can be provided as a multi-level set of writing and drawing tools. The writing and drawing capabilities available to a student are selectable by the student or teacher. A last general
25 tool is a link-maker, which offers exercises in various types of memorization, such as paired associates, serial learning, ordered serial learning, and mnemonics. Finally, additional tools can be added to an implementation to meet specific educational needs. For example for geography lessons a map
30 tool can be added. For student projects, an encyclopedia tool and a network search tool can be added. The Study Buddies™ can provide instruction in operation of the tools such as the use of keywords and operators. Specialized tools can be added for commercial or industrial training.

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